Anders Stene

Use of Augmented Reality in Aquaculture

Augmented reality based operator interface for enhanced positioning and decision support during UID operations related to net inspections and repair in aquaculture

Master's thesis in Cybernetics and Robotics
Supervisor: Anastasios Lekkas, Esten Ingar Grøtli and Aksel Andreas Transeth
June 2019

Master's thesis

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Preface

This thesis conclude my Master of Science in Cybernetics and Robotics at the Norwegian University of Science and Technology(NTNU). The project was carried out during the spring semester of 2019 in collaboration with Sintef Digital. The main supervisor of the project is Anastasios Lekkas, but all guidance and supervision during the project have been given by Esten Ingar Grøtli and Aksel Andreas Transeth at Sintef Digital. I want to thank Esten and Aksel for giving me a lot of freedom carrying out the project, while still providing ideas on how to progress the project through interesting discussions.

The thesis contain findings, and detailed description of systems and experiments completed, to test if augmented reality(AR) could enhance ROV operations related to aquaculture. The inspiration of this project is the growing use of AR in professional industries such as oil and gas, medical and manufacturing. Today, AR is an untouched field related to aquaculture, and could potentially reduce cost, save time and add support in ROV operations. The experiments conducted will test and evaluate performance and usability of two AR systems aimed to support the operation of fish cage net inspection and repair. Detailed descriptions of the AR systems and experiments are carried out in the thesis, together with a presentation of important theory related to the drone operations in aquaculture, AR and usability testing.

The main contributions of this thesis are the two AR systems that have been developed to show how an AR system could be helping and give added decision support during underwater operations in aquaculture; The AR INFO system and AR INTERACTION system. The AR INFO system was developed to investigate how AR could enhance data gathering and handling during inspections, while the AR INTERACTION system was developed to research how AR could add support in interaction operations such as net repair. The AR systems and experiments can potentially add ideas and inspiration on how to further develop an AR system related to operations in aquaculture, and how to evaluate and test such AR systems. In the end of the thesis, a proposal of an improved system is given, based on the findings and evaluations conducted in the experiments. A broader discussion on how AR could be used in the best way to enhance operation, is elaborated and presented.

Since the project offered a large degree of freedom, choice of software, planning the experiments and the testing procedure, and how to evaluate the systems, were an open task. The AR systems were implemented in the game engine Unity[1] using the AR library Vuforia[2]. All the scripts are completed in the programming language C# using Visual Studio. All components and hardware related to the experiments, including AR markers, are designed and created by myself. 3D objects in the experiments have been designed in the CAD program Creo Paramterics[3] and 3D-printed with the help of personnel at the workshop of the Department of Cybernetics at NTNU. The 3D-printed objects are described in detail in the section 4.1 where the experiment setup is described. To evaluate the systems the NASA-TLX app[4][5] were used to measure the workload experienced when using the systems in the project. Identifying the NASA-TLX evaluation as a suitable way to evaluate the AR systems, was a task done by myself without any recommendations from the supervisors. During the experiments, screen recording of the video feed from the systems and objective observations were conducted. From ideas and inspiration of state-of-the-art usability testing, a self made subjective evaluation were made to evaluate the the AR systems after the experiments were conducted.

To carry out the experiments in the project, the university have provided me with the necessary tools. The following is a list of all tools and equipment provided by the university as a basis to complete the experiments and research of this project:

- A Dell Optiplex 9010 computer and a large work desk with storage space for equipment, at disposal at NTNU.
- A test room where I could create the experiment setup, were provide from the university. The test room were large enough to create the experiments in a suitable manner.
- Real fish cage nets used in the experiments to create realistic test scene related to aquaculture. The nets were provided by the Department of Cybernetics.
- Cardboard and plywood plates to create the test wall and parts of the docking used in the experiment setup were provided by the workshop of the Department of Mechanical Engineering at NTNU.
- A Logitech Webcam C925e used in the experiments were provide by the Department of Cybernetics.

Despite carrying most of the project myself, guidance sessions with Esten and Aksel have given me the opportunity to discuss and present the work done. They have provided me with ideas on how to progress further in the project, and offered great guidance in how to structure the report. Through the project, I have learned a lot, and I hope that the work would be useful for other that want to work with similar issues.

Acknowledgement

I would like to thank my supervisors at Sintef Digital, Esten Ingar Grøtli and Aksel Andreas Transeth, for all the guidance and help during the project. Through interesting discussion, new insight and perspectives have been gained to further progress the work of the project. Further, I want to thank fellow graduate students for inspiring discussions and help received throughout these years. Lastly, I want to thank my family for the support and encouragements that they have been giving me throughout this journey. The last five years have definitely been an unforgettable experience.

Anders Stene
Trondheim, 03.06.2019

Summary

In augmented reality, computer-generated objects are used to enhance the perception of real-world experiences, through added clarity and data. In the last years, the technology have been gaining popularity, especially in development of mobile apps, but also in industry applications. Industries such as oil and gas, military and manufacturing have seen the advantages that AR may offer through added support and instructions during operations. An industry that has yet to explore the benefits of AR is aquaculture. AR have the potential to reduce cost, save time and enhance support in underwater drone operations such as net and mooring inspections. With AR the control personnel may achieve a better overview and more efficient completion of the operations through added AR information. To increase the production of fish, aquaculture sites have to be located further from land at more exposed places[6]. This increases the need of reliable technology that could make benefits related to remote operations and surveillance with manual or autonomous drones, and AR is a promising technology in that regard.

This thesis aims to explore how AR could enhance the underwater ROV operation of fish cage net inspection and repair. Two AR systems have been implemented to explore, test and evaluate different kinds of ways to use AR in net inspections and repair: The AR INFO system and AR INTERACTION system. The AR INFO system is implemented to look at how AR could achieve enhanced handling and displaying of information under inspections of the net. The AR INTERACTION have been implemented to see how AR could be used to enhance support in interaction operations such as net repair. The AR systems are evaluated separately, conducting two different experiments: The INFO and INTERACTION experiments. In the experiments test persons solve a set of different tasks using both an AR system and a system without AR. The tasks are almost the same for both systems, but some adaptions have been made to make the test procedure of the two systems comparable. The system without AR works as a benchmark, to evaluate if the AR system achieve better performance and usability. In chapter two of the thesis, relevant theory related to drone operations in aquaculture, AR and usability testing are presented. In the following chapters both AR systems and experiments, with test procedures, are described in detail.

One of the main contributions of this thesis, is the concept sketch and proposal of an improved AR system based on the findings and evaluations of the AR systems implemented in the thesis. The AR systems in the thesis have been evaluated through different kinds of evaluations. The NASA-TLX app have been used to accurately evaluate the workload of the systems. Screen recordings of video feed from computer used in the experiments and objective observations have been gathered during the experiment. After the experiments, the test persons have conducted a subjective evaluation, evaluating the AR systems based on usability goals described in detail in section 2.5.1. The main result was that the AR system must have a simplistic user interface to avoid information overload,

and that only AR components that contribute directly to the operation should be part of the AR system. Supporting information is best suited as static UI text on a panel of the screen, and not as augmented components in the scene. The proposed, improved AR system may contribute to new ideas and inspirations on how to implement an AR system related to remote underwater interaction drone(UID) operations in aquaculture.

Throughout this project, AR have shown to be a promising technology for operations in aquaculture. The AR INTERACTION system performed better than the system without AR in the categories related to completions time of tasks, workload and usability. Nevertheless, the AR INFO system got a more mixed response. In parts of the experiments, the test persons suffered from information overload decreasing the performance of the AR system. All the results are presented and discussed in the *Results* chapter. The goals of implementing, testing and evaluation AR systems aimed towards net inspection and repair are assumed achieved. The results obtained from the experiments, show that the AR systems have a way to go related to usability and performance, but that the implementations offer a basis for further enhancements of the AR systems. Discussion on bias and validity of results conducted in the experiments, as well as how AR could be used in the best way to enhance operations in aquaculture, are presented in the end of the thesis. Suggestions for further testing of AR related to ROV operations in aquaculture are also presented.

Sammendrag

I utvidet virkelighet(eng: Augmented reality) brukes datamaskin-genererte objekter og visualiseringer til å forbedre oppfatningen av virkeligheten, gjennom å legge til mer klarhet og data. I løpet av de siste årene har teknologien økt i popularitet, spesielt innen utvikling av mobilapper, men også innen industri og næringsliv. Industrier som olje og gass, militær og helsesektoren har sett hvordan AR kan gi fordeler gjennom mer støtte og instrukser under operasjoner. En bransje som har igjen å utforske fordelene til AR er oppdrettsnæringen. AR har potensiale til å redueres kostnader, spare tid og forbedre støtten i undervannsoperasjoner med drone, som for eksempel nett- og fortøyningsinspeksjon. Med AR kan kontrollpersonell oppnå bedre oversikt og mer effektive gjennomføringer av operasjoner gjennom AR informasjon. Hvis produksjonen av fisk skal økes, må oppdrettsanlegg lokaliseres lengre fra land, på mer utsatte plasser[6]. Dette øker behovet for pålitelig teknologi som kan gi forbedringer i fjernstyring og overvåkning med manuelle eller autonome droner, og AR er en lovende teknologi i forhold til dette.

Målet med denne avhandlingen er å utforske hvordan AR kan forbedre drone operasjoner relatert til inspeksjon og reparasjon av fiskenettet på merden. To AR system har blitt implementert for å utforske, teste og evaluere hvordan AR kan brukes i nettinspeksjon og reparasjon: AR INFO systemet og AR INTERACTION systemet. AR INFO systemet er implementert for å se hvordan AR kan oppnå bedre behandling og visning av informasjon under inspeksjon av nettet på merden. AR INTERACTION systemet har blitt implementert for å se hvordan AR kan brukes til å forbedre støtten i interaksjonsoperasjoner, sånn som nettreparasjon. AR systemene er evaluert hver for seg, gjennom to forskjellige eksperimenter: INFO eksperimentet og INTERACTION eksperimentet. I eksperimentene tok testpersonene å løste et sett med oppgaver ved å både bruke et AR system og et system uten AR. Oppgavene er nesten de samme for begge system, men noen tilpasninger er gjort, slik at testprosedyren for de to systemene er sammenlignbare. Systemet uten AR fungerer som en målestokk, for å se om AR systemet oppnår bedre funksjon og brukervennlighet. I andre kapittel blir relevant teori relatert droneoperasjoner innen oppdrett, AR og testing av brukervennlighet presentert. I påfølgende kapittler blir begge AR system og eksperiment, med testprosedyrer, beskrevet i detalj.

En av hovedbidragene i denne avhandlingen, er konseptskissen av et forbedret AR system basert på funn og evalueringer av AR systemene implementert i dette prosjektet. AR systemene i dette prosjektet har blitt evaluert gjennom forskjellige typer evalueringer. NASA-TLX appen har blitt brukt til å måle arbeidsmengden man opplever når man bruker systemene. Skjermopptak av video feed fra datamaskinen brukt i eksperimentet og objektive observasjoner har blitt samlet under eksperimentet. Etter eksperimentene, har testpersonene gjennomført en subjektiv evaluering, som har evaluert AR systemene basert på brukervennlighets-mål beskrevet i detalj i kapittel 2.5.1. Hovedresultatet fra evalueringen var at AR systemene må ha et enkelt brukergrensesnitt for å hindre at systemet ikke

gir brukeren for mye informasjon på en gang, og at bare AR komponenter som direkte bidrar til å gjøre operasjonen lettere, bør være en del av AR systemet. Støttende informasjon passer best å ha som statisk UI tekst på et panel på skjermen, og ikke som AR komponenter. Det foreslåtte, forbedrede AR systemet kan bidra til nye ideer og inspirasjon til hvordan man kan designe og implementere et AR system relatert til fjernstyring av undervanns-interaksjons droner(UIDer) innen oppdrettsnæring.

Gjennom dette prosjektet har AR vist seg å være en lovende teknologi for operasjoner innen oppdrettsnæring. AR INTERACTION systemet gjorde det bedre enn systemet uten AR i kategoriene relatert til gjennomføringstid av oppgavene, arbeidsmengde og brukervennlighet. På den andre siden fikk AR INFO systemet en mer delt tilbakemelding. I deler av eksperimentet, led testpersonen av at AR systemet, i kombinasjon med testprosedyren, ga for mye informasjon på en gang. Noe som gjorde at AR systemet gjorde det dårligere enn systemet uten AR i disse segmentene av eksperimentet. Alle resultatene fra eksperimentene er presentert og diskutert i *Results* kapittelet. Målet med å implementere, teste og evaluere AR systemer rettet mot nettinspeksjon og reparasjon er antatt oppnådd. Resultatene gitt fra eksperimentene viser at AR systemene har mer å gå på når det gjelder brukervennlighet og funksjon, men at implementasjonene gir en basis for videre forbedring av AR systemene. Diskusjon relatert til partiskhet og validitet av resultatene fra eksperimentene, i tillegg til diskusjon rundt hvordan AR kan bli brukt på best mulig vis til å forbedre operasjoner i oppdrettsnæring, er presentert nærmere slutten av avhandlingen. Forslag til videre testing av AR relatert til ROV operasjoner i oppdrettsnæring er også presentert.

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Abbreviations

AR	=	Augmented reality
CV	=	Computer vision
UID	=	Underwater intervention drone
SDK	=	Software developer kit
AEC	=	Architecture, engineering and construction

Chapter 1

Introduction

The information and theory presented in the chapter *Background and motivation* are mainly taken from the candidate's specialization thesis called *Augmented reality(AR) with underwater intervention drones in aquaculture*[19]. Nevertheless, some adjustments and changes have been made to suit the purpose of this thesis.

1.1 Problem description

Net inspection and repair are one of the most common operations performed at the aquaculture sites. Today, ROVs are doing most of the inspection, while professional divers must do the repair part of the operation. The operation of repairing the holes at the net could be a dangerous operation, if the weather conditions are challenging. Utilizing the emerging technology of AR could help introduce better depth perception and decision support capabilities between the interface of ROVs and operators, enabling robust ROV operations performing both inspection and repair of the net.

The following research questions and problems will be explored in this master thesis:

- Could AR enhance ROV operations related to net inspection and repair at the aquaculture site?
- What kind of AR content could be beneficial to the operation of net inspection and repair? And what kind of AR content is not beneficial?
- How could AR be used in the best way enhancing the operation of net inspection and repair at the aquaculture sites?

1.2 Background and motivation

In 2014, according to a report from Marine Harvest, the world population was 7.2 billion people, were 870 million people did not have enough to eat. In 2050, the estimated world population have increased to 9.1 billions, and if the supply of food have not increased the number of people with not enough food will keep going up. The sea covers the earth surface by approximately 70 percent, yet only 2 percent of the worlds food supply comes from the ocean [7]. Hence, the potential of supplying the world with food from the ocean is massive.

Norway is one of the biggest export nations of seafood in the world. In a report from the Norwegian seafood council[20] shows that in 2017 alone, the exports was worth a record-high of 94.5 billion NOK. Most of the increase in income came from rising prices in salmon, which stood for 68.4 percent of the revenue. It is estimated that the value creation of the Norwegian aquaculture in 2030 and 2050 will be approximately 119 billion NOK and 238 billion NOK, stated in the report *Value created from productive oceans in 2050*[21]. The Norwegian government has great ambitions for the industry, and have for example initiated a project called *Target 2025*[22]. The main goal of the project is to increase the value of Norwegian seafood export to China to 10 billions RMB in 2025. Another goal is to increase the consummation of salmon in China to 156 000 tons, and the consummation of cod to 40 000 tons, by 2025. It is possible to produce up to 5 million tons of fish by 2050[6], if important challenges related to production and environment get solved. To reach these goals and ambitions, the industry is dependent on new innovations for increased efficiency and precision.

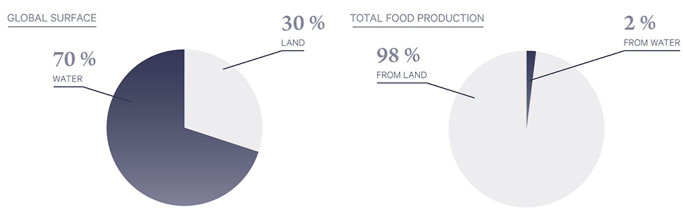


Figure 1.1: Total food production and global surface distribution between ocean and land[7].

In Norway, a lot of research are committed on the field of aquaculture. A big research project called *Exposed* is focused on fish farming of salmon and trout at exposed locations at the Norwegian coast[6]. Fish farming at exposed locations demand new technical solutions to secure safety and reliability. The project is a meeting platform for big companies like Marine Harvest and SalMar, and research institutions like Sintef and NTNU, to explore and discover solutions for demanding maritime operations at exposed locations. A supporting technology that could enhance safety and clarity at exposed locations, and at plants in general, is *augmented reality*. Today, all operations like net maintenance, fish inspection and anchor repair, are either done by drones or professional divers. The future of sites in aquaculture are unmanned[23]. Then, all processes are either done autonomously or by remote controlling. To achieve unmanned sites, drone must be used for interventions at the sites. Augmented reality can provide more clarity for drone pilots through better visualization and added information. AR can provide live data and interactive perception while doing repair and maintenance operations at the remote sites.

One problem during drone operations at the fish farming are related to depth perception. All the data from the drone are presented at a 2D monitor, while the drone is interacting in the 3D world. The transformation where 3D data is presented on a 2D monitor, make it hard to visualize the depth at the 3D scene correctly. During the operation of net inspection and repair, the perception of depth is crucial for avoiding collisions and precisely manipulating the desired object(fixing the holes by sewing or attaching a temporary net). This thesis will look at the possibility of using AR to enhance the operation of net inspection and repair, by utilizing the possible benefits of AR such as better depth perception, added decision support and a more streamlined information flow during operation.

In the industry, this research could be interesting for companies in aquaculture. Augmented reality could potentially reduced cost, and achieve making it easier achieving operations further from land at exposed places. Since little research have been conducted on AR related to aquaculture, the information and results in this thesis could be of interest for researchers wanting to expand their knowledge within the field.

1.3 Goal and method

The main goal of this thesis is to investigate how AR could enhance net inspection and repair operations by exploring and answering the research questions and problems defined in the *Problem description* section. To explore and investigate the use of AR, a goal is to implement one or more AR systems to explore the possibilities of utilizing the benefits of AR in ROV operation in aquaculture. Another goal is to test and evaluate the AR systems towards a system containing no AR. The system without AR will work as a benchmark, to see if the AR performs better in the categories of workload, usability and performance. The comparison between the systems with and without AR will create a basis for discussing and answering the problems defined in the *Problem description* section.

Since AR is an untouched field within aquaculture, another goal is to present detailed description of AR systems and experiments, to provide ideas and inspiration on how to implement, test and evaluate AR systems related to ROV operations in aquaculture. Further, based on the results and evaluation of the AR systems, a goal is to create a proposal of an improved system which could work as a summary of what kind of AR content that works and should be forwarded, and what kind of AR content that is not beneficial and should not be implemented in AR systems of the future. The last goal, is to offer a broader discussion on how AR could be used in the best way enhancing support in operations in aquaculture, based on findings from experiments, testing and evaluation of the AR systems implemented. The goal is to offer new ideas and inspiration on how AR systems could be used in ROV operations performing net inspection and repair at aquaculture sites.

The implementations of the AR systems are done in the game engine *Unity*[1]. To enable AR functionality in Unity, the AR library *Vuforia*[2] is used. In Unity, using Vuforia, the AR components are designed, and functionality added through scripting in the programming language *C#*. To test the system, a test setup will be created, and a suitable number of test persons will conduct the experiments created. The test persons will do the test procedure with both an AR system and a system without AR for comparison. Relevant theory and background will be presented and conducted through a literature review.

To evaluate the systems and experiments, different evaluation will be conducted during and after the experiments. To monitor the performance and important metrics such as completion time, screen recording will be conducted during the experiments. To measure workload, the test persons go through a *NASA-TLX*[24] evaluation after each section in the test procedure. To evaluate the performance and experience of the test persons during testing, objective observations are gathered. After the experiments, the test persons complete a subjective evaluation evaluating the performance, usability and design of the AR systems. Results are presented, and findings in the testing and experiments will form a basis for further discussion on the challenges and possibilities of the use of AR in net inspection and repair operations at aquaculture sites.

1.4 Contributions

The following list is a description of the contributions made by this project:

- **Two AR systems** have been implemented related to net inspection and repair. The first system called *AR INFO system*, was implemented to investigate how information could be displayed to support inspection of the fish cage net. The other AR system called *AR INTERACTION system*, was implemented to explore how AR could add support related to depth perception and decisions support in the interaction operation of net repair. The AR systems are described in detail in chapter 3.
- **Detailed descriptions of experiment setup and testing procedure** of the two experiments conducted: The *INFO experiment* and the *INTERACTION experiment*. The INFO experiment compares the performance, usability and workload of the AR INFO system compared to a system without AR. The INTERACTION experiment compares the performance, usability and workload of the AR INTERACTION system compared to a system without AR. Both experiments are conducted with test persons completing a similar set of tasks using the systems of the experiments. The experiments are described in detail in chapter 4.
- **A proposal of a complete, improved AR system combining the two AR systems implemented**. The concept sketch is created on a basis of the findings and evaluations from the experiments conducted. The improved system proposed are merging all the AR content, and is able to add support to ROV operation of both inspection and repair. The proposal is created to offer new ideas and insight, and to summarize the findings of the experiments into a concept sketch of an actual AR system that could be implemented. The proposal and concept of the improved system can be found in chapter 5.3.
- **A broader discussion**, offering ideas and insight on how AR could be used in the best way to enhance ROV operations in aquaculture, based on the findings, results

and evaluations done in the experiments. The discussion tries to answer and elaborate on the research questions and problems defined in the problem description. In this discussion, important aspects of the experiments conducted, how to test AR and validation of the results are elaborated and discussed. The discussion can be found in chapter 6, and the specific discussion related to the use of AR in ROV operations can be found in chapter 6.2.

1.5 Outline of report

The report is organized as follows:

- **Chapter 2**: The chapter presents relevant background and theory related to the project. Theory related to fish farming, ROV operations in aquaculture, AR and usability testing are presented. In the end of the chapter, tools and libraries used in the project are elaborated.
- **Chapter 3**: Design and implementations of the project are given. The implementations entails both the AR systems implemented, and the AR markers created and designed.
- **Chapter 4**: Detailed description of the setup and testing procedure of the two experiments conducted are given. Assumptions and limitations for each of the experiments are elaborated, as well as detailed description of the evaluations conducted throughout the experiments and testing.
- **Chapter 5**: Results from both experiments are presented and discussed. The results elaborated and discussed, are based on the evaluations conducted in the experiments. In chapter 5.3, a proposal of an improved AR system is given, based on findings and observations from the experiments.
- **Chapter 6**: The chapter contain an overall discussion of the experiments, testing procedure and validity of results. In the second part of the discussion chapter, is it elaborated and discussed how AR could enhance operations in aquaculture in the best way. The discussion is focused on answering the research questions and problems defined in the *Problem description* section.
- **Chapter 7**: The chapter concludes the thesis, and present a list of suggestions for further work.

Chapter 2

Background and theory

This section present findings from a literature review focused on fish farming, ROV operations in aquaculture, AR and usability testing of AR systems. Large parts of the sections *Fish farming*, *Augmented reality* and *Marker-based versus markerless AR* are taken directly from the specialization project *Augmented reality(AR) with underwater intervention drones in aquaculture*[19]. Information are added to the sections, and adjustment and enhancements have been made to suit the purpose of this thesis.

2.1 Fish farming

This section is presented to give the reader a brief overview of the fish farming industry, which is the industry that the AR implemented in this thesis is aimed for. Further, an elaboration of the relevant operations focused on in this thesis, net inspections and repair, will be presented to give the reader an overview of todays situation regarding this operation.

Norway have a long coast line, and along this coast line there are many fish farms. These sites can be located near the coast or further out at more exposed places. A fish farm contains a fish cage, where the fish swim freely in fresh and clean seawater. At bigger plants, a control room is placed offshore at the site. Normally, control rooms are located onshore or on a control ship. Shipping boats are used to transport equipment and tools to and from the site. The nutrition of the fish is precisely measured from the control room offshore or onshore.

The activity of the fish is monitored by a camera. If the activity is high, this means the fish need more food, and if the fish are more calm, necessary nutrition have been ensured. To avoid disease, specifically related to lice, the salmon gets antibiotics to remain resistant. At these sites there are often inspections of the fish, and maintenance and repair of the fish net and anchoring of the site. Today, all operations related to maintenance and inspection are done by manually driven drones or professional divers.

Figure 2.1: Regular fish cage with control room in the background[8].

The number of fish in a cage can vary from a couple of thousands to SalMars mega site called Ocean Farm 1[25], that contain about 1.5 million fish. So far, Ocean Farm 1 is the largest site at the Norwegian coast with a height of 68 meters, diameter of 110 meters and a total volume of 250 000 cubic meters. SINTEF, in company with SalMar, Marine Harvest and Cermaq[6], has fish farms offshore for scientific purposes. The site at disposal is located at one of SalMars facilities in Norway. The measures of the net cage is 80x50x10 meters. The tank is used for science projects related to the welfare of the fish, how to increase production and testing of new technology. Hence, the facility is used for both biological and technical research.

2.1.1 Net inspections and repair

In the master thesis *Analysis of current ROV Operations in the Norwegian Aquaculture*[26], the author is giving a detailed descriptions of drone operation performed in aquaculture today. This subsection will briefly describe one of the most regular operations performed by drones today, which is net inspection and repair. The operation of net inspection and repair is the operation emphasized in this project. A more detailed description of the operation can be found in the paper mentioned above.

The most frequent type of operation performed by drones in aquaculture today is inspections. These inspections often involve net or mooring inspections. These operations must be performed often, to ensure quality and robustness of the fish cage. During net inspections, the drone check if the net have any holes, or other deviations, that could lead to fish escaping. The drone drives around inside the cage checking every part of the net. During inspection the drone is generally very close to the net. In cases with bad visibility, the drone could be as close as 0.5 meters away from the net. The distance is most often 2-3 meters, keeping good distance while clearly seeing the net. One net inspection could take from half an hour to three hours, dependent on factors like weather conditions and size of the cage inspected. How frequent the net inspection are done is dependent on how often the specific companies book these services. Some companies have net inspections once every third month, while others have inspection twice a month.

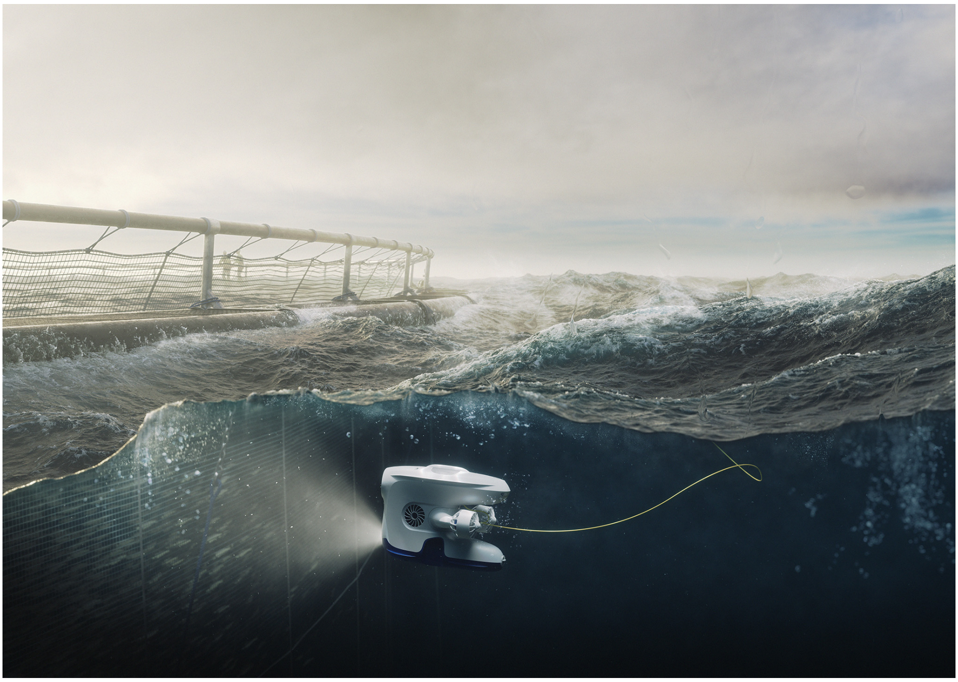


Figure 2.2: A drone called *BlueEye Pioneer*, developed by the company BlueEye, inspecting the net at an aquaculture site[9].

Holes and fractures of the net could be caused by a variety of things. Something could lay against the net, causing gnawing, and hence wear out the net. Bigger fish could be biting the net to get access to the fish cage for food. Collisions of drones with the net could occur, and cause fractures or larger damages. If any holes, fractures or other type of deviations are detected by the drone, they are resolved as soon as possibles after they are detected. In most cases, a professional diver is fixing the hole permanently. It could often take up to two hours before the divers arrives to fix the hole permanently. In the meanwhile the drone is covering the hole to make sure no fish escapes. The company Deep Trekker have developed a net repairer[27], that could repair the hole temporary using a ROV before the professional divers fix the hole permanently. If the holes or other damages are detected at the side of the net, the net could easily be fixed by lining up the net and fixing it at the surface. Divers are most often used if the hole is far down on the side or at the bottom of the fish cage net.

Net inspections could be challenging operations to complete. The weather and sea

Figure 2.3: The drone with a *Net Repairer tool* developed by the company Deep Trekker.

conditions could make it hard to investigate the net in a suitable manner. Strong ocean currents make it hard to navigate the drone so that the video feed from the operation is stable enough for proper inspection. The visibility underwater could also be bad, caused by high levels of turbidity in the water. Under water the darkness could cause interruption in the operation. Light and colors disappears dependent on the depth of the water, decreasing the visibility. Using artificial light underwater may attract or stress the fish, causing the operation to be interrupted. To solve this challenge, the personnel uses low-light cameras, or LED lights which can be used at low intensity. The drone may also collide at objects in the fish cage such as cameras, ropes or fish food-suppliers. Collisions happens rarely, but is something the personnel must be aware of during operation.

2.2 Augmented reality

A report from the American tech company *newgenapps*, estimates that by 2020 there will be about 1 billion users of augmented reality, with a market volume of 150 billion dollar[28]. Inside the gaming community, it is estimated that 216 million players will take part in the AR world. *In the next chapter the focus will be on the fundamentals, theory and use of AR in the world today. The sections are presented to give the reader an overview of the technology used in this thesis, as well as the innovations and use of the technology in a various of industries. This will give the reader a base understanding on the situation of AR in the world today, and why it may be possible to use this technology enhancing the aquaculture industry.*

2.2.1 Fundamentals of augmented reality

Augmented comes from the word augment, which mean *to add* or *enhance something*[29]. The main concept of augmented reality is to add to or enhance the view of the real-world, by adding superimposed computer-generated objects and images over the users view of the real-world. Hence, enhancing the users view of reality through added clarity and interaction. The augmented overlay of the generated effects is executed in real-time and simultaneously with the input from the camera. The user of AR can interact with the technology through many ways, such as mobile screens, desktops, head mounted displays or smart glasses.

Augmented reality have many beneficial features, that could be used in a wide range of applications. These features include:

- Visualizing and communicating various content.
- Simplification of real-world structures that needs more explanations.
- Data flow and interactive perception in real-time.
- Automatic capture of reality with overlay of advanced technology, enhancing recognition.

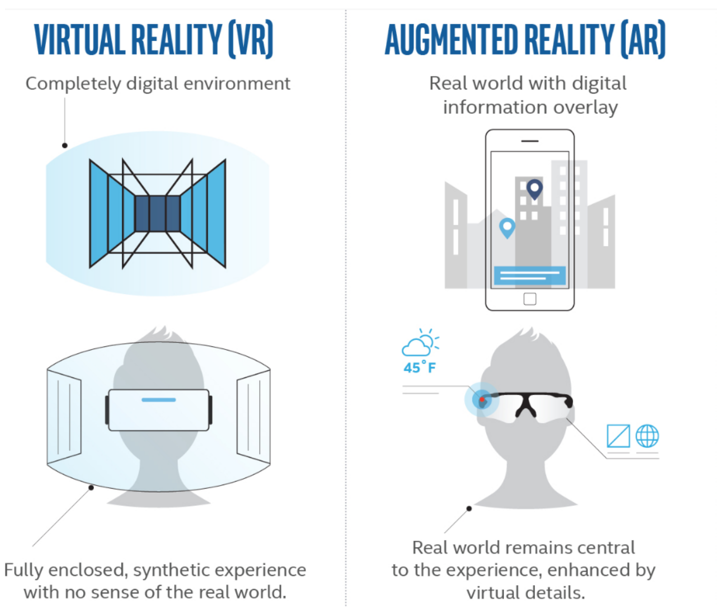


Figure 2.4: Virtual reality versus augmented reality[10].

How is augmented reality different from virtual reality? In virtual reality, or *VR*, the user is part of an entirely virtual environment. When using VR, everything the user see is generated by a computer. In augmented reality, the user interact with the existing, natural environment, and visual information is overlaid on top of the real-world view. Therefore, the difference of these technologies is the degree of the virtual content in use to create the perception for the user.

A system that uses AR contains of three parts[29][30][31]:

- Hardware
- Software
- Remote servers

Important hardware components in AR applications are processor, displays, input devices and sensors. The display options for AR is primarily monitors, mobile screens, smart glasses or head mounted displays(HMD). The input device is some sort of camera. It could be a camera on a phone, web cam or a camera attached to a drone. Sensors make it possible for the AR device to get position, orientation and other measures necessary to create the augmented experience. To create augmented reality, intelligence have to be added to the camera, so that objects in the real-world can be detected and interacted with. To achieve this, computer vision(CV) software must be used to get the correct tracking and localization of objects relative to natural surroundings. Virtual imaging, used for the overlay, can be designed and generated using 3D software. The remote server stores everything needed of data for the application.

2.2.2 Overview of the use of AR

Many sectors have started to take use of augmented reality in different kinds of operations. These applications varies from fun games to serious inspections at industrial plants. The situation today, is that the use of AR can be divided into two sections: Personal mobile AR and professional industrial applications. There are many successful AR apps available today, and new innovations and use cases are explored rapidly.

Mobile AR

With the introduction of *Pokemon GO* in 2016, augmented reality started to get real traction in the mobile apps industry. In the application, the user could go for a hunt on pokemons by locating the pokemons in a real-world map. The catching of the pokemon happened through an AR experience; the overlay of a virtual pokemon could be seen in real-world environments through the screen of a smart phone. The game became very popular, and reached 800 million downloads in April 2018[32].

With new games getting rolled out every week, the AR technology have shown to be a critical component to further game development. The estimation is that by 2025, 216 million gamers will interact with some sort of AR or VR technology. Large companies like Apple and Google have introduced their own software development kits(SDKs) aimed towards mobile AR, respectively called *ARKit* and *ARCore*. For developers, these platforms make it easy to make games through open-source code, detailed API documentation and collaboration with other developers.

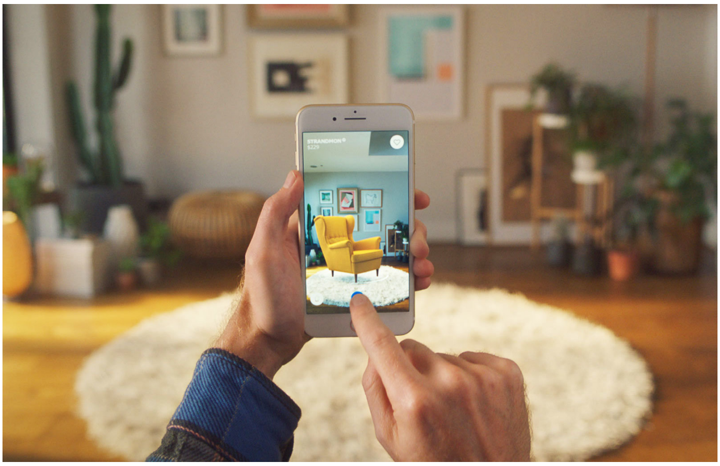


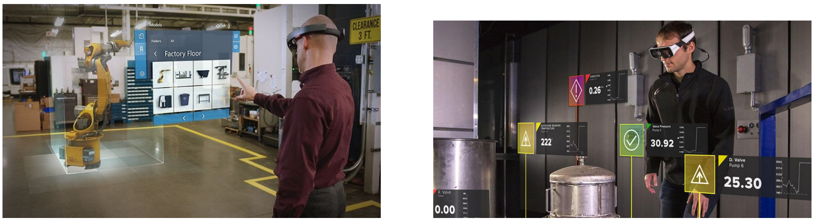
Figure 2.5: Augmented furniture is placed in the room using *IKEA Place*[11].

The mentioned SDKs are about the same, and give the developer great possibilities of making a good AR mobile application. Some of the traits that these platforms offers are persistent AR experiences, possibility of shared AR experience and robust object detection and tracking. There are a wide variety of possible applications that can be made from these SDKs, ranging from games to real estate. For example IKEA made an AR game called *IKEA Place*[33], where the user could virtually place IKEA furniture in its own living room, to see how the furniture would look like before buying it. Another example is the app called *Streem*[34], that give instructions of the use of home appliances through the use of AR. These are only two out of many applications that can be found in Apple *App Store* or Google *Play Store*.

Industrial applications

The AR technology are starting to gain real traction in professional use and traditional sectors like military, health care and civil engineering are looking into the possibilities in using AR. One of the main innovations of AR used in industry is the *Microsoft HoloLens*[12]. Microsoft HoloLens is a headset that is attached to the user, and it is wireless, meaning that all the computer power is at the back of the headset. Mixed reality content is shown in real time, and the user can interact with visual objects by tapping, or other suited gestures. Microsoft HoloLens can be used for a variety of different applications, like to show a miniature of a planned architectural building, getting instructions from a Skype call or give status reports on critical components at an industrial plant.

Another example of the same technology is the *DAQRI smart glasses*[13]. These smart glasses are specialized in professional applications and supporting the user with informa-



(a) **(b)**

Figure 2.6: Both Microsoft HoloLens(a) and DAQRI smart glasses(b) are promising for industrial applications[12][13].

tion and intelligence through environmentally-based data in real-time. The main use of the smart glasses is related to support with in-depth information in construction, process industry and engineering. The company behind the smart glasses have partnered with big companies like *Amazon* and *SAP*.

With the introduction of AR headsets and smart glasses, new and innovative applications can be developed. In the paper *Augmented Reality: Applications, Challenges and Future Trend*[35] many applications and research areas are discussed. Below are some important sectors and applications:

- **Medical**: AR enable the doctor to visualize medical data, while simultaneously focusing on the patient. The technology is used in ultrasound imaging; through an optical see-through display the technician can see an image that appears to be from inside the body. The rendered image get updated in real-time as the professional's head moves. AR can also be used for visual guidance during surgical operations, and the surgeon can interact with the visuals by hand gestures. Hence, this can increase precision and ensure better hygiene.

- **Military**: AR can be used to create artificial battlefield scenes, hence used for training soldiers going to war. Big scale scenarios can be played out, with enemy actions simulated in real-time. In the battlefield, AR can be used for intervention planning and visual communication between operatives. Another application is the see-through display on fighter plane helmets. These visuals can provide accuracy in targeting, or display status information of the plane in real-time.

- **Manufacturing**: AR can support the assembly process by providing graphical assembly instructions and animations sequences in real-time, and in parallel with the actual assembly. These visual instructions can be requested by the user, and a visual overlay of the product is then presented in an instant, with associated instructions. Advantages of this approach are that information overload can be avoided and a decreased in needing for assistance from other persons. A study conducted on the assembly with overlaying instructions using AR[35], found that the error rate for an assembly task was reduced by 82 percent when using visual overlay compared to traditional assembly using a printed manual.

- **Education**: Displaying key information and visual objects at the same time as perceiving reality, enable visualization of complex relationships and abstract concepts in math, physics or chemistry. Computer generated visuals can make it easier to grasp the law of physics, show reactions between chemical substances or display help and tips while doing math problems. Being able to work on the information hands-on, can make it easier for many students to learn and grow with the content.

The use of AR is flexible, since the output data can be shown in many ways through monitors, headset or smart glasses. With the innovations of headsets and mobile phones, the technology can be used practically everywhere, with few constraints. This means more people can get the support needed in day-to-day work from AR, providing useful data in parallel with real-world operations.

2.3 Marker-based AR

This section gives an overview of the theory and process behind marker-based AR. The difference between marker-based and markerless AR is presented. The section also elaborates on when it is suitable to use marker-based AR in a perspective of testing AR related to aquaculture. This section is presented to give the reader a brief overview of the AR technology used in this thesis, marker-based AR, and the chapter Marker-based AR: When to use? is added to give reasons why marker-based AR could be suitable for testing and evaluating AR systems related to operations in aquaculture. The chapter is presented to show why marker-based AR is used in this thesis, and to present proposals and suggestions of further work. Large parts of the section Marker-based versus markerless AR is taken from the specialization thesis written by the author of this thesis[19]. Adjustments and enhancements are made to suit the purpose of this thesis.

2.3.1 Marker-based versus markerless AR

There exists many different types of AR, with different technologies and objectives. Often AR get divided into two broad types: Marker-based AR and markerless AR[29][36]. Marker-based AR, or image recognition, uses a camera and one or more active or passive visual markers, such as a QR code, to display augmented effects when the marker is detected by the AR algorithm. These distinct, simple patterns are easily detected and do not need a lot of processing power to read. To detect these markers the necessary software is pre-programmed into the AR device, and the marker help the AR device to determine position and localization of the camera. The pose(position and orientation) of the marker relative to the camera is calculated, and is used to correctly place the augmented content relative to the marker with correct position and scale. An example could be a museum, where the user can point the camera of the phone to a marker at an information plaque. When the marker is detected, data and augmented, visual effects may instantly pop up to show more about the specific artifact.

Figure 2.8 shows the pipeline of marker-based AR. From the video stream of the camera, the algorithm is searching for markers to detect by converting the image to binary

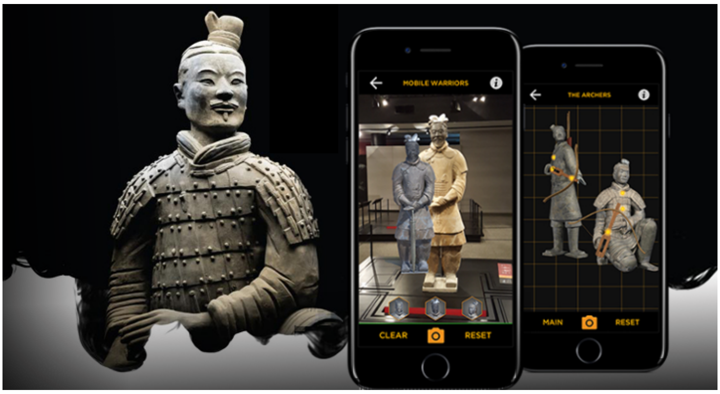


Figure 2.7: Marker-based AR at a museum[14].

image. When a marker is detected, the 3D position and orientation of the marker relative to the camera are calculated. The pose of the marker is organized in a transformation matrix that contain all the information of the position and rotation of the marker. Then the encoding of the AR marker is used to identify the marker, to show the correct augmented info in front of the marker. When the AR marker is encoded, the correct pose and scale of the virtual object is calculated using the transformation matrix that have the information on pose of marker relative of camera. When the pose of the virtual object is calculated, the virtual object is rendered and is shown in the video stream as augmented content.

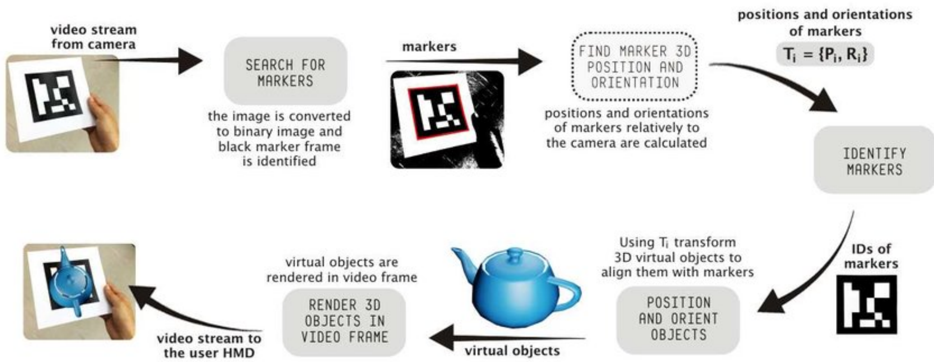


Figure 2.8: The pipeline of marker-based AR[15].

With markerless AR, nothing is pre-programmed into the AR device. Instead, the AR device need to used a combination of sensors and computer vision to detect and display virtual content. Example of sensors could be GPS, digital compass, velocity meter or gyroscope. The great advantage of using such technology is the increased flexibility and autonomy. An example of this technology could be the wildly popular game *Pokemon GO*[32] by the company named Niantic. The application uses GPS to track geographical data, the clock of the phone to determine when and where to make Pokemons appear and accelerometer and compass to orient the camera relative to the Pokemon. The augmented reality is displayed through a overlay of a Pokemon, suitable placed in the real-world surroundings.

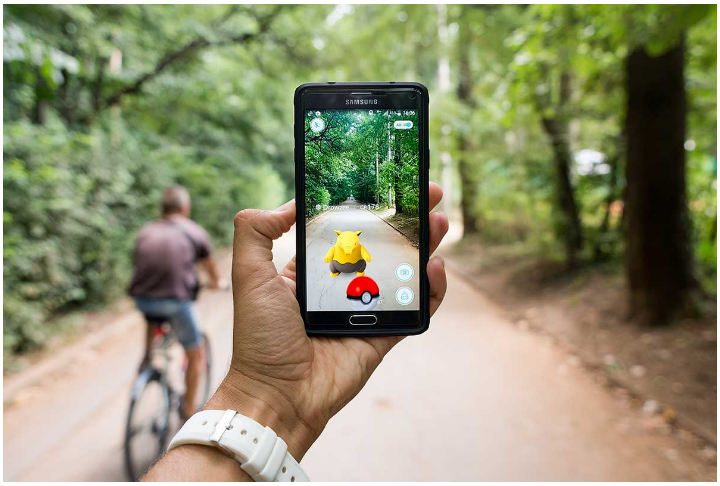


Figure 2.9: The Pokemon GO app in action[16].

To achieve AR in large-scale, non-restrictive areas where the desired location of the AR content is unknown, markeless AR offers a better solution through its flexibility and autonomy. With no need for markers, the augmented content can be displayed everywhere with the help of sensors and computer vision. Nevertheless, the algorithm behind such solution will be complex and require a lot of processing power, since the recognition algorithm running in the AR application has to identify keypoints, patterns or other features in the camera frames.

When the area is restricted and well known, and the location of the AR content is established beforehand, marker-based AR provides greater robustness and reliability. Using a marker with well known descriptors(keypoints and features) as an ”anchor” in the real world, makes the pose estimation more robust and accurate. Hence, AR markers are easily detected and tracked. A solution using marker-based AR will require substantially less processing power, and should be preferred if the AR application does not require full autonomy.

2.3.2 Marker-based AR: When to use?

In this section we are going to look at different situations and environments where marker-based AR is to prefer over markerless AR or feature-based tracking. Further, the different situations will be related to aquaculture, where the benefits of using marker-based tracking are shown.

Siltanen[37] offers a list of scenarios where marker-based tracking is a good choice of solution in his thesis *Theory and applications of marker-based augmented reality. For each situation the benefits related to aquaculture are elaborated, and only relevant scenarios for aquaculture, and this project, from the list will be presented and elaborated. The elaboration could be used by researchers looking for ideas on reliable ways to test AR related to aquaculture.*

1. *Tracking in environments that are challenging for feature tracking*
   Large uniform areas are often hard to track in using feature-based tracking since the scenes contain non or a small number of features. These scenes are highly ambiguous and applying markers will enhance tracking performance in such environments. Environments with repetitive textures are also hard to track using features, since these scenes contain many similar features making it hard to obtain pose from unique geometric matches. In drone operations doing net inspections, the net have the same size of the different net-masks making the scenes contain only repetitive features. Hence, feature tracking will be hard to perform. Markers may achieve better estimation of pose, tracking and making it possible making AR content in such environments.

   Dynamic texture such as the net of the fish cage moving dependent on the ocean currents, may be hard to track cause of the change in location of features. This is also relevant when doing operation of the anchoring of the fish cage, since these structures may oscillate dependent on ocean current. Applying markers will make it easier doing detection and tracking in such operations, since attaining the pose relative to a marker is independent of the ocean currents.

2. *Acquiring the correct scale and a convenient coordinate frame*
   A solely feature-based tracking system, with no external sensors, cannot obtain the scale from the scene. Only relative proportions are derived, and the scale is fixed if the distance between two objects is known. In a marker-based tracking system the physical dimension of the marker is known, hence the correct scale can be deduced. Achieving correct and precise depth perception during operations in aquaculture, obtaining the correct scale is crucial. If objects, like specific structures on the anchoring or holes in the net, appear bigger than they are, performing maintenance and manipulating such objects will be impossible.

   Without any additional sensors, feature-based tracking cannot deduce earth coordinates from the perception of the scenes. The result is that origin and coordinate directions are random. For the drone to properly orient itself in the fish cage, the deduction of earth coordinates must be done. This can be achieve using markers that are strategically placed. With markers the earth coordinates can be deduced, and the drone then knows what direction is *up* or *down*, *vertical* or *horizontal*. This is information that must be known for creating robust AR applications.

3. *Environments with lots of moving objects and occlusions*
   Scenes with many moving objects occluding the background, are difficult to handle

using feature-based tracking. An example from aquaculture, is fish moving randomly in front of the net during inspection and maintenance. A heavy steam of fish may cover large parts of the scene causing loss in tracking. Another problem is that the moving objects itself may contain features that make the tracking system track unnecessary features. All these scenarios is causing loss in tracking, and marker-based tracking provide more robust solutions.

4. *Need for extra information*
   Additional information can be stored in a marker such as ID or URL. Associated data can the be attached to the marker, and information can be retrieved. Feature-based tracking can not provide additional information in such way. If for some reason information cannot be stored in a database, the marker can have attached information that is stored locally. This is relevant for net and anchor inspection where different holes that need to be fixed get their own ID for later reference, then information about when the hole was detected, how urgent it is to fix among other things, can be displayed using AR content. Components on the mooring can also get the same system of different IDs containing info on status, last inspected and how urgent an operation is.

5. *Efficiency*
   Since marker-based systems are less complex and require less computational power, the systems are better suited for testing and prototyping. Demonstration applications use in a proof-of-concept experiment, instead of emphasizing the tracking and performance, may be easier to achieve using marker-based over feature-based methods. The concept of efficiency is important in this thesis, since the project emphasizes testing AR in aquaculture through doing experiments using prototypes.

6. *Environment with existing markers*
   Environments already containing markers could be used beneficially to ensure robust tracking. Markers strategically placed on the net or mooring could help the drone to determine pose of AR objects presented at fixed locations. These markers are naturally part of the environments but serves as markers related to the AR.

7. *Indication of the existence of virtual data*
   The markers visuals itself indicated existence of virtual data to the control personnel. Placed markers in the fish cage or at the mooring indicate that additional virtual information can be displayed. This makes it easy to divide between areas with and without AR content.

Marker-based tracking is beneficial in a variety of different situations and environments. Most of these scenarios are parts of the underwater experience of fish cages. Hence, marker-based AR is a promising technology for testing and prototyping achieving robust and accurate AR systems used in ROV operations in aquaculture.

2.4 AR markers

To achieve optimal identification and tracking, great AR markers must be chosen for the application. In AR, the markers create an interface between the physical world and the augmented content. An AR marker is more generally known as a *fiducial marker*; *any object that can be placed in the scene to provide a fixed point of reference of position or scale*[38]. Markers are needed to calculate the pose(position and orientation) of the camera to the device creating the AR content. When the pose is known, AR objects can be placed in the physical world in an accurate way, with correct scale and position. Since marker tracking is achieved using only visual information, without any sort of external sensors such as a gyroscope or accelerometer, the quality of the AR marker is crucial for creating robust AR applications.

This section will presented the theory and guidelines used in designing and creating the AR markers used in the experiments and testing in this thesis. The first part gives the reader an overview of what makes a good marker, and what criteria that have been emphasized creating AR markers for robust tracking and detection in this project. The second part of this section, introduces challenges related to using AR markers in underwater AR, presented to form a basis for further discussion on how to progress AR related to underwater operations in aquaculture.

2.4.1 Characteristics of good AR markers

In the official developer guide of Vuforia, an overview of traits of a good AR marker is given in the article *Optimizing Target Detection and Tracking Stability*[18]. With Vuforia, markers can be made from any image called *Image targets*. In the article three specific features are specified for a marker to be easily identified and tracked:

- Rich in detail
- Good contrast between the different regions in the marker
- No repetitive patterns

A marker that is low in details, will simultaneously be low in features and make it hard to track. To achieve robust identification and tracking, many features must be detected to establish the pose. In an image or marker, objects with sharp edges with many features are preferred over organic shapes with soft and round details. Examples of scenes that are rich in detail are class pictures, images from sport or collages. These images contain parts that are highly different and full of sharp edges and mixture of different items. Another thing to look at is how the features are distributed in the marker. Images with small areas with a high concentration of features may be harder to identify and track, since the tractable part of the image is considerable smaller than the untrackable part of the image. For optimal identification and tracking, an image containing features that are uniformly distributed is preferred. In the article *What Makes a Good Marker*[39], the size distribution of the features is pointed out as an important factor regarding tracking. A marker with only small scale features, will be more vulnerable when blurring occur or with large distances between the camera and marker. The problem can be solved by adding features in a variety of different sizes. Then tracking will be more robust since large scale features will still be visible on large distances or if blurring occur.

To detect the features in the marker, strong contrasts between regions of the marker is crucial. A marker with strong contrast has regions with dark and bright regions, distinct change in color or shade and great brightness. To make feature tracking easier, the local contrast between each region must be strong. To achieve this, it it preferred to chose markers that have regions that are more edged over markers that have round details, are blurred or highly-compressed.

A marker with repetitive patterns suffer from bad detection performance. Individual objects in the image can be detected and matched with other objects, but the repetitiveness make it hard to calculate the pose of the marker, due to many similar relations. To have robust identification and tracking in rough conditions, and overall coherent geometric relationship between the matches from the camera images and the marker must be established[39]. Similar patterns could be confused with each other, making the calculation of the pose incorrect. Hence, it is preferred to avoid markers with repetitive patterns and strong rotational symmetry[18] completely.

To have proper tracking of the marker, the size of the marker must be considered. If the marker is to small in relation to the distance from the camera, the tracking will be less robust. Vuforia gives a rough estimate of how you should determine the width of the marker:

$$\text{Width of marker} = \frac{\text{Camera-to-target distance}}{10} \tag{2.1}$$

However, as it is pointed out, this is a rough estimate, and highly variable dependent on factors such as light conditions and camera performance. The viewing angle is also an important factor to keep in mind. If the test environment or applications has a setup where the marker is at a steep angle or oblique relative to the camera, detecting and tracking marker features are harder. An optimal setup require the marker to be as parallel as possible with the camera lens, displaying most of the marker to the camera for detection and tracking.

Another things to take into consideration are the flatness and glossiness of printed markers. The tracking of the printed marker can decrease substantially in performance if the marker is not flat. If the marker bend or coil up, finding features could be hard to achieve. It is recommended using ticker paper or cardboard when printing the markers, instead of regular printing paper. Glossiness of the printed marker may also cause problems. Light sources such as lamps or the sun can cause glossy reflections covering large parts of the marker. The features in these parts will then be impossible to detect, and hence identification and tracking fails. This is not a problem under ambient lighting conditions, but should be considered when working in test environments with different kinds of light sources. Lighting conditions for optimal experiments should be stable and easy to control, with enough light showing scene details and marker features.

2.4.2 Challenges of using markers in underwater AR

They main challenge when displaying AR content underwater is challenging light conditions. Deformations of the light in water is causing effects such as absorption, scattering, blurring and non-uniform lightning[40], making it hard to detect and track AR markers.

When light passes from one medium to another, the light bends in an effect called *refraction*[41]. Refraction causes objects to appear approximately 25 percent larger and closer than they really are, when light travelling through water and hits the glass and air of the lens of the underwater camera. This is a challenge regarding camera calibration, and finding the correct intrinsic parameters handling this problem. The phenomenon is also causing blurry scenes, since refraction can make it difficult for the camera to focus properly on the object. Robust AR applications underwater must handle refraction, through adaptations regarding calibration and camera performance.

Another challenge is lack of light underwater, due to *light absorption*. When light is travelling through water about half of the light is lost for every 10 meters of depth[41]. This means that the light is absorbed quite quickly making it hard to achieve enough natural light for AR applications. This could be solved by applying artificial light sources such as a strobe, but again this may cause problems related to glossiness of marker or scattering. Weather is also an important factor to take into account. In a storm, the oceans currents are heavy making the water absorb more light, hence decreasing visibility even further. When the depth is larger than 10 meters, small proportions of natural light is left. Fish cages are often much deeper than 10 meters, and then the challenge with artificial light prevail.

Using AR markers with colors introduce the challenge with *color absorption*. Light with shorter wavelength get faster absorbed by the water. This means that color like yellow, orange and red are fast omitted by the water, than colors like blue and green coming from light with longer wavelengths. Most colors are fully absorbed at a depth of around 3 meters. Blue is the color reaching the farthest with a depth reach of 24 meters before everything turns black. To implement an AR application using AR markers with colors is challenging if only artificial light is available, and since fish cages are substantially deeper than 3 meters one have to consider using a strobe or be critical when selecting regarding the colors used in the AR marker.

In underwater AR, and AR in general, the *occlusion problem* is a hard task to handle. Occlusion happens when a 3D object blocks another 3D object[42]. The problem is that, currently, an AR object cannot be occluded naturally behind a real world object. This is a problem, since it makes the AR object look out of place and not naturally located. The occlusion problem may cause problems for the AR content in a fish cage. With the fish moving randomly, it is hard to determine the position of the fish at any time. The fish may be in front of the marker causing loss in tracking, and setting the inspection operation on hold. Another problem is when the fish are occluded behind the AR content, when it is not supposed to, making the AR content making more harm than good. Yet, there is left to make a solution that fully solves the occlusion problem. The depth sensors of today are too slow, have limited range and low resolution to work in real-time occlusion[43]. Some possible solutions related to Marker-based AR used in museum tours are proposed in the article *How to Work Around Occlusion Issues in Augmented Reality*[44]. But these solutions concerns rather temporary solutions such as masking objects beforehand and having visitors placed at specific places where occlusion does not occur. Nevertheless, these solutions comes up short when dealing with dynamic objects in real-time, such as fish, in UID operations underwater.

2.5 Usability testing of AR systems

To evaluate the AR systems in this project, various evaluations were conducted under and after testing the the AR systems. To get ideas and inspiration on how to create a framework for evaluation the AR systems, different papers on usability testing of AR systems have been reviewed. In the thesis *Usability Evaluation for Augmented Reality*[45], usability testing of different kinds of AR systems are presented. In the thesis, the author present a way of testing AR systems with *structured tasks*. Structured tasks are created by the experimenter, and is a step by step to-do list which the test person performs in order to complete the task. The test procedure in this thesis came from this idea of having a set of tasks the test persons perform, and then evaluate the performance and usability of the AR systems.

To properly evaluate the AR systems, a subjective evaluation with suitable questions and statements have been made. Ideas and inspiration on which questions and statements to ask the test persons have been conducted from different papers. A study[46] is using a questionnaire with statements to evaluate an AR system giving instructions in a hospital setting. The statements in the thesis worked as a basis on the work of creating the statements in the evaluation of this thesis. Another thesis[47], is looking at usability evaluation of an AR system related to educational applications. In the study, several questions and statements related to effectiveness, efficiency and satisfaction of the AR system are presented in a questionnaire to the test persons. The test persons are also asked how the AR system could be beneficial in their experience related to learning and studying. This thesis provide more ideas on which statements and questions to use in the subjective evaluation used in this thesis. The thesis did also introduce the idea of linking the questions in the evaluation to different kinds of defined usability goals. The idea of asking the test person *in what way* the AR system were beneficial came from the thesis.

The papers presented, together with the usability goals presented in the section below, created the groundwork on how the AR systems are evaluated in this thesis.

2.5.1 Usability goals

The usability goals works as a guideline to evaluate different aspects of the usability of a system. To evaluate the AR systems described in this thesis, six different usability goals are defined and used. From the ISO-9241 standard(ISO 1998)[48], the three usability goals *effectiveness*, *efficiency* and *satisfaction* are defined. The usability goal of *learnability*[49] is used to evaluate how easy it is to learn the AR systems. Because of their relevance to AR systems, the usability goals of *workload*[50] and *situation awareness*[51] are added and used. The selected usability goals covers the most important usability aspects of AR systems, and are suitable to evaluate the usability and performance of the AR systems. The definition of each usability goal were used as guidelines and inspiration to what kind of questions to ask related to the evaluation of the AR systems. The subsections below will describe what each usability goal entail.

Effectiveness

In the ISO-9241 standard the usability goal of effectiveness is defined as *"accuracy and completeness with which users achieve specified goals"*. The effectiveness refers to how accurately and completely the AR system is able to perform its intended task. The usability goal could be measured in different ways dependent on which task the AR system is doing. If the AR systems main task is gathering or displaying information, it could be measured how necessary and helping the displayed info is. If the AR system is used in an interaction operation, it could be measured how much the AR system is helping completing the interaction tasks in an accurate way. The participants could also be asked to rate their own success related to the task through a questionnaire. Evaluating the goal this way, could lead to less validity of the results, since people cannot be expected to evaluate their own success in an objective and accurate way.

Efficiency

The ISO-9241 standard define efficiency as *"resources expended in relation to the accuracy and completeness with which users achieve the goals"*. Efficiency is the amount of time and resources used when using the AR system. This usability goal could be evaluated through the completion time the test person uses to complete a specific task using the AR system.

Satisfaction

The usability goal of satisfaction is defined as *"freedom from discomfort and positive attitudes towards the use of the product"* in the ISO-9241 standard. Satisfaction is the subjective evaluation on how satisfied or pleased the users was using the AR system. To evaluate the degree of satisfaction, a questionnaire or survey with question related to the goal could be used.

Learnability

Learnability is how easy it is to learn using the AR system. This could be related to the information flow of the AR system, or how easy it is to interact with the AR information displayed from the system. Learnability could be measured through a questionnaire or survey with questions related to the usability goal, like *"How easy was the AR system to learn?"* or *"How fast did you get familiar with using the AR system?"*.

Situation awareness

Situation awareness relates to the users ability to be aware of, and understand the situation of the operation in the environments using the AR system. Using AR systems related to drone operation, the user is not physically present at the drones location. The users perception of the operation is not through direct observation,, but a live video-feed from the operation. Thus it may be difficult to maintain a high degree of situation awareness. This usability goal could be measured in three different ways; explicit, implicit and subjective[52]. Explicit evaluations are performed by pausing the experiment to quiz the user about their knowledge of the location of the drone and the situation of the operation. A drawback of this way of testing situation awareness, is that the pausing could interfere the testing in other parts of the experiment. Implicit evaluations are measurements of metrics that may indicate the situation awareness. In drone operations, the number of collisions could be a relevant metric. A larger amount of collisions could indicate the the situation awareness of the operation is low. Subjective evaluations concerns questionnaires or surveys, where the test person subjectively evaluated the situation awareness of the operation using the AR system.

Workload

The workload relates to how demanding, both mentally and physically, it is to use the AR system to perform a specific task. If the AR system require more physical activity to display the AR info, the physical workload will increase. The workload will also increase if the AR system present large amounts of information to be perceived and understood by the user. If the workload become to high, this may cause the performance to decrease and the probability of making incorrect decisions will increase. Workload could be measured through metrics that are assumed correlating with workload. Such metrics could be the number of commands or instructions given from the AR system, the amount of physical work that have to be done to make the AR system work properly during operation or the amount of AR information the user must handle during the operation.

An often used method to evaluate the workload is the NASA Task Load Index(NASA-TLX) survey[24]. This technique is not specifically defined to test workload related to AR system, but is commonly used to evaluate the workload of a wide variety of experiments and tasks. The evaluation procedure can be done on a computer, through the pen-and-paper version or the NASA-TLX app[4][5](used in this project). The NASA-TLX survey is a multi-dimensional rating procedure that computes the overall workload of a specific task based on a weighted average of ratings on six sub-scales: Mental demand, physical demand, temporal demand, performance, effort and frustration. All the sub-scales with official descriptions are presented in Table 2.1. The three first dimensions relate to the demand imposed on the user when completing the tasks(mental, physical and temporal demand), while the three last dimensions relates to the users interaction with the specific task(effort, frustration and performance).

The evaluation procedure of the NASA-TLX survey is divided into two different parts consisting of weighting and rating each sub-scale, and then in the end of the evaluation the overall workload is provided by combining the result from the two sub parts of the survey. A subject ID is given to each participant completing the survey, to easily organize the results. The first part of the survey consist of evaluating the contribution of each factor(its weight) to the workload of a specific task. To assign the weight of each factor, 15 possible pair-wise comparisons of the six scales are presented to the participant. The subject then chooses the factor in each pair that contribute the most to the workload. The number of times the specific factor is chosen are counted by the program, and indicates the contribution of the overall workload of that specific factor. The weight ranges from 0(not relevant) to 5(the factor contributing the most to the workload).

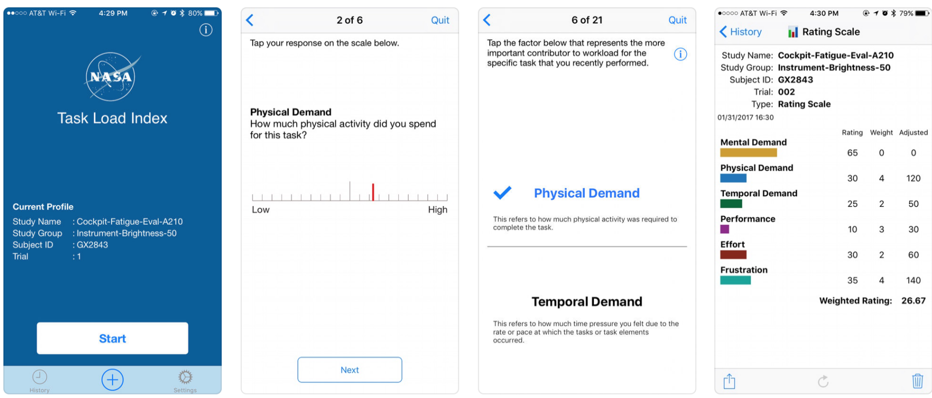


Figure 2.10: The screen shots of the NASA-TLX app. The screen-shot to the left is the front page of the app. In the middle are screen shots showing the procedure of assigning ratings(left) and weights(right) to each factor. To the right is the screen shot presenting the results from the survey. *This illustration is gathered directly from the presentation of the NASA-TLX App in App Store[17]*

In the other part of the survey the subject give numerical ratings to each scale, that indicates the magnitude of that factor in a given task. In the rating part of the survey, each factor is presented with an associated scale. Each scale is presented as a line divided into 20 equal intervals anchored by bipolar descriptors(for example *High/Low* or *Good/Poor*). The participants give ratings to each factor by marking each scale at the desired location. The evaluation survey of NASA-TLX could be done during tasks, after task segments or after entire tasks. In the end of the NASA-TLX survey, the results are presented. The overall workload score for the subject completing the survey is computed by multiplying

Factor	Endpoints	Descriptions
Mental demand	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical demand	*Low/High*	How much physical activity was required(e.g., pushing, pulling, turning, controlling, activating etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal demand	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Effort	*Low/High*	How hard did you have to work(mentally and physically) to accomplish your level of performance?
Performance	*Good/Poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Frustration	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Table 2.1: The six sub scales used in the NASA-TLX survey.

each rating by the weight given to that factor by the subject. The score of the overall workload, the sum of the weighted ratings of each task, is divided by 15 which is the sum of the weights. If the task is easy or hard to accomplish mentally and physically, the score of the workload is low or high accordingly.

2.6 Tools and libraries

In this section, the software and hardware used in this project are presented.

2.6.1 Software

Unity

Unity[1] is a game engine created by Unity technologies, and first announced and released in June 2005. The platform can be used to create 2D and 3D games, as well as it offers great simulation tools. The engine gives great real-time performance, and is a trusted developer engine for many companies in a variety of industries such as automotive and transportation, AEC and advertising and marketing. Development and scripting are done in the programming language C# using Visual Studio. The engine is compatible with both Windows and MacOSX and extended to support 27 different platforms. In this project the engine was used as a platform creating the AR systems, with extended support from the AR software *Vuforia*. Unity offers paid licenses such as Unity *Pro* and Unity *Plus*, and a free license with Unity *Personal*. Since this project is for educational purposes(and not seeking for any revenue), the free version *Personal* was used for the project.

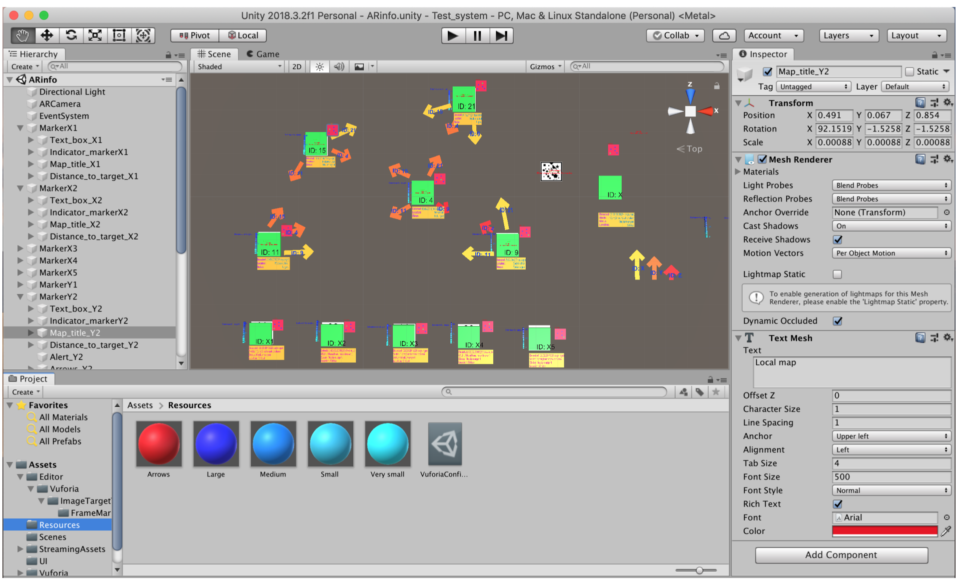


Figure 2.11: The Unity user interface, with the component hierarchy on the left, inspector to the right, project overview with resources at the bottom and main scene editor in the middle.

Vuforia

Vuforia[2] is a software development kit(SDK) for creating augmented reality experiences for mobile and industry. Industries like manufacturing, service and sales and marketing have taken use of AR technology from Vuforia. The development kit is optimized for marker-based tracking, and supports many different kinds of 2D and 3D markers. *Image targets* enables the user to make AR markers out of any kind of image as long as they follow the guidelines for optimal detection and tracking described in the section *Characteristics of good AR markers*. Multi-marker detection is supported. Vuforia is pre-installed and compatible with the latest release of Unity. In this project, Vuforia enabled development of the AR content. The AR development included creating AR markers and storing them in an online Vuforia database, setting up the different scenes in Unity using an AR-Camera with developer license from Vuforia and then performing tracking of the markers and setting up the AR content using the resources from the developer kit. The engine performs camera calibration automatically.

Creo Parametric 3D Modeling Software

Creo Paramateric[3] is a CAD platform where the end user can design, document and analyze 3D-models for parts and assemblies. The platform runs on Microsoft Windows, and offers powerful and flexible tools for 3D direct modeling, schematic design, technical illustrations and visualization. In this project, the platform where used to design 3D-objects that were later 3D-printed and used in the setup of the experiments. The 3D-objects designed where various attachments and docking used to more easily operate the hardware of the test setup. The experiment setup and 3D-objects are more detailed described in the *Experiments and testing* chapter.

Google Forms

Google Forms[53] is an online form builder created by Google, where the end user can make surveys and evaluations. The survey can be made with different kind of questions such as multiple-choice, scale and comments sections. The forms are easily shared with participants through mail, and all results are saved in the cloud using Google Disk. Answers from participants can be shown individually and as a summary containing the answers from all the participants. In this project, Google Forms was used to create the subjective evaluation of the AR systems, and the multiple-choice form used in the test procedure in one of the experiments conducted.

2.6.2 Hardware

Logitech Webcam C925e

Logitech Webcam C925e[54] was used in the experiments and testing of the system. The webcam offers Full HD 1080p 30 fps ensuring good performance in real-time. It is compatible for Windows 7 or newer and Mac OS X 10.7 or newer. The camera is certified for usb 2.0 offering great transmission speed, and is easy to use with USB plug-and-play.

Chapter 3

Design and implementation

Throughout this project, two AR systems have been developed and tested. Both systems have been developed in *Unity* using the library *Vuforia*, and all the scripts are written in the programming language *C#* using Visual Studio. The first AR system, called *AR INFO*, was developed to test if AR could be used to gather important information from holes on the fish cage net faster than traditional methods in aquaculture. The second system, called *AR INTERACTION*, was developed to test if AR could be used to provide added support in interaction operations in aquaculture. To display and present the AR content, using marker-based AR, AR markers have been created during the project. In the next sections both the two AR systems and the AR markers created, will be described in detail.

3.1 AR INFO system

The AR INFO system was developed to test if AR could be used to gather important information from holes in the fish cage net faster and more directly. At different distances from the target/holes, the AR system display different kinds of content to add support in navigation and displays important information about already detected holes on the fish cage net. C# scripts configuring the AR content of the system, are presented in Appendix A.1.

3.1.1 AR INFO: Configuration

In this section, the different AR content presented at different distances from the hole are described in detail. The distance from target indicate the distance from the camera used for inspection and the AR marker attached at the hole. All the AR content described in this section are presented when the system algorithms are identifying the AR markers described in detail in the section *AR markers*.

At a distance larger than 40 cm from the hole, a large ID Board in light green color is showing. The green color is in great contrast to the environment, making it easy to located

Distance from target	AR content: Illustration	Description
Distance > 40 cm		Indicator board with ID.

Figure 3.1: Configuration of the ID Board

the position of the hole. On the ID board, the ID of the hole is shown in black text. Since the black text is in great contrast to the green background, the ID of the hole is easy to read, even at large distances. The AR marker and the hole itself are occluded behind the ID board at this distance. The reasons for this, is that at a distance larger than 40 cm away from target, it is more important locating where the hole is, since the camera is to far away to do any proper investigation of the hole. The large ID board in bright colors make it easy to locate the hole at large distances. At this stage of the inspection, locating the hole is more important than investigating it. Since several holes could be in the video frame at larger distances, simultaneous tracking of multiple holes is relevant. The AR system is able to track the position of three holes simultaneously, making it easier for support personnel to get an overview of the inspection at larger distances from the net.

Figure 3.2: The ID board shown during testing. The bright colors of the ID board make it easy locating where the hole is.

At a distance between 30 cm and 40 cm from the hole, arrows indicating nearby holes are showing in addition to the ID board described above. At this distance, it is harder to get a great overview of where the different holes are. The arrows is added to help locating where nearby holes(one to four holes) are and how far they are from the current hole inspected. The arrows are shown in bright colors in strong contrast to the environment,

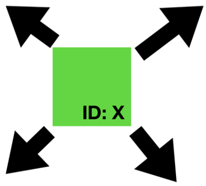
Distance from target	AR content: Illustration	Description
30 cm < Distance ≤ 40 cm		Indicator board with ID. Arrows that show nearby holes. Length of arrows indicate distance to nearby holes.

Figure 3.3: Configuration of ID Board with arrows

making it easy to get the direction to the nearby holes. On each arrow the ID of the hole located in the specific direction is written in large and bright colors, making it easy for the operator to decide which holes are nearby.

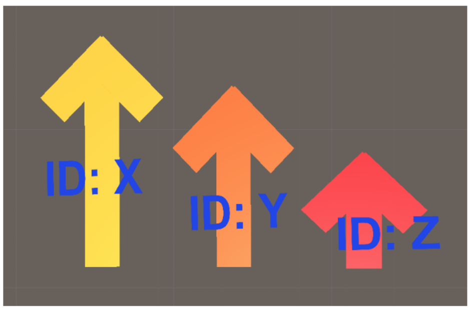


Figure 3.4: The AR arrows with different lengths and colors.

The length and color of the arrows indicate how far away the different nearby holes are. The longest arrow in yellow color indicate that the specific nearby is in a range between 78 cm and 110 cm away from the current hole inspected. The medium long arrow in orange color indicate that the specific nearby hole is in a range between 45 cm and 77 cm away from current hole inspected. At last, the red arrow indicate that the nearby is less than 45 cm away from the current hole inspected. The arrows with different colors and lengths make it easier for the personnel to get a clearer picture on how far away the different holes are, and the direction to the different holes. Hence, the arrow may provide more efficient navigation on the net during inspection. The distances between the holes in the test scene are much smaller, than realistic distances between holes at an actual aquaculture site. But the arrows are implemented to show an alternative solution on how to make navigation easier during inspection of the net.

At this distance, the hole is still occluded by the ID board. The distance is still to large to achieve any proper investigation of the hole. The location of the hole is still more im-

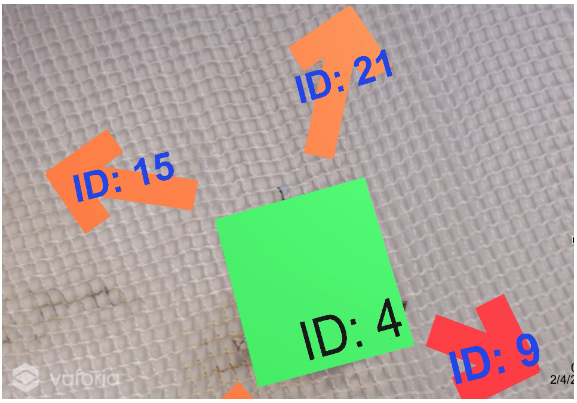


Figure 3.5: ID board with the arrow indicating nearby holes. The orange arrow indicate that the nearby holes with ID: 15 and ID: 21 are in a range of 45 cm to 77 cm away from the current hole with ID: 4. The red arrow indicate that hole with ID: 9 is less than 45 cm away from current hole.

portant, than investigating the hole directly. The arrows are added at this distance since the overview of the net has decreased, and the arrows may help achieving faster correction if the personnel is looking at the wrong hole. All in all, the arrows are added at this distance for easier and faster navigation on the net during inspection.

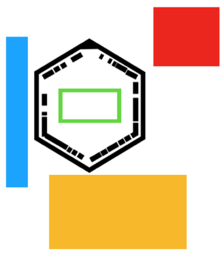
Distance from target	AR content: Illustration	Description
Distance ≤ 30 cm		Yellow: Statusboard presenting relevant information about the hole. Blue: «Distance to target»-bar showing how far the camera is from the target. Red: Local map, showing position of nearby holes relative to current hole inspected. Green: Outline of hole w/size (width x height in centimeters).

Figure 3.6: Configuration of AR components used during net hole inspection.

At a distance less or equal than 30 cm away from the hole, different AR components are showing. The different AR components have their own configuration, and are created to support the personnel investigating the holes directly. The AR components have bright colors making it easy to set them apart from the surroundings. At this distance the AR marker and hole are not occluded, and in the Figure 3.6 the AR marker is the black figure shown. The AR marker is a frame marker, meaning that all the encoding to identify the marker is around the hole like a ”frame”, so that the hole itself is showing through an opening in the middle of the marker.

Attribute	Type	Description	Value/format
Detected	Date/string	Indicated when the hole was detected, and how long since it was detected.	02.02.2019 Detected 36 days ago
Location	String	How critical is the location of the hole?	Not critical Medium critical Critical
Status	String	How urgent is the repair of the hole?	Not urgent Medium urgent Urgent

Table 3.1: Important attributes of the holes presented by the status board of the AR system.

In the middle of the AR marker, an outline in bright green color is indicating the location and size of the hole. Above the outline the size of the hole is presented as *width x height* in centimeters. The outline make it easier for the personnel to visualize the hole, and retrieve the size of the hole directly. The bright green color make it easy detecting and visualizing the hole. Under the AR marker, a status board is presenting important attributes of the hole. The status board with associated text is made in bright colors in great contrast to the environments. This AR component is especially important to be in high contrast to the environment, since the personnel must read and take out crucial information about the holes. Hence, the colors chosen contribute to high readability. The different attributes of the hole shown on the status board is described in detail in Table 3.1.

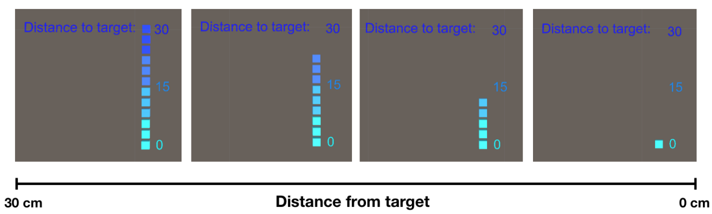


Figure 3.7: The configuration of the augmented ”Distance to target” bar

To the left of the AR marker and hole, a ”Distance to target”-bar is showing. The bar indicate the distance between the camera and the hole. The range of the bar is from 0 to 30 cm. The bar itself contain of 12 augmented cubes. When the camera is approaching the hole, the cubes at the top of the bar starts disappearing with the camera moving with an interval of 30/12 = 2.5 cm. If the camera is moving away from the hole, the cubes will appear again. The colors of the cubes disappearing will get lighter the more closer the camera is to the hole, and darker when the camera is moving away from the hole. During testing, the range of the bar was 0 to 50 cm, but after testing the system, findings show that better overview of the inspection is ensured if the range of the direct inspection of the holes happens in a distance range of 0 to 30 cm.

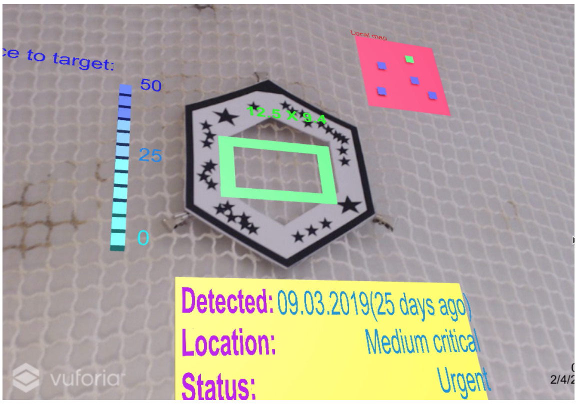


Figure 3.8: The AR system during testing. During testing the range of the distance bar was from 0 to 50 cm away from the hole, while during the experiment the range was changed to 0 to 30 cm from target. The range was changed based on results and observations during testing, since the new range provided better overview during inspection.

In the upper right corner relative to the AR marker and hole, the local map is presented in a bright red color. The local map indicates where other nearby holes are relative to the current hole, and offers almost the same function as the arrows showing at larger distances away from the hole. In the map, the current hole is shown in a green color in bright contrast to the red background. Nearby holes have the color blue, and relative distances between the holes are shown in miniature in the map. The local map offers a overview of the nearby area of the net, and could contribute to easier and faster navigation for personnel during inspection. The size and scale of the local map are carefully chosen so that great readability is ensured.

Distance from target	AR content: Illustration	Description
Distance < 10 cm	**Careful!** **You are getting very close!**	Alert indicating that the camera is very close to the net, to hinder collisions with the net.

Figure 3.9: Configuration of the AR alert.

At distances less than 10 cm away from target, an alert is showing indicating that the camera is getting very close to the net. An alert is created to hinder collisions to happen, and to be a *"last call"* warning to the personnel that they may collide and should move further from the net before continuing the inspection. The alert is presented in a large and bold text with a red color.

Figure 3.10: The AR alert showing during testing.

3.2 AR INTERACTION system

The AR INTERACTION system was developed to test if AR could help support personnel in interaction operation in aquaculture. An examples of such operation is hole repair, where the drone is interacting directly with the net to get it fixed, like using equipment like the *net repairer tool*[27] by the company Deep Trekker mentioned in the *Theory and background* chapter. C# scripts configuring the AR content of the system, are presented in Appendix A.2.

In the experiment, using this AR system, the test person will go through a specific procedure:

1. The test person detects the hole.
2. The test person finds the color of outline displayed on the hole, and the size of the hole.
3. The test person finds the marker with the color matching the color on the outline of the hole. This marker have a net attached to it, to fix the hole temporary.
4. The test person achieves the goal of the operation by attaching the marker w/net to the AR marker on the hole to fix the net temporary until the net can be fixed permanently.

The interaction in the test scene is done by the test person operating a stick with a camera and magnet attached at the end of the stick. The description of this procedure, and the experiment in general, is described more in detail in the chapter *Experiments and testing*. In this section the AR system will be in focus. To achieve or enhance the procedure described above, the AR system developed display different types of AR content to give necessary information and positioning support to the test person. The AR system is described in detail in the next section.

3.2.1 AR INTERACTION: Configuration

In this section, the different AR content appearing during the procedure given earlier in this section is described in detail. The appearance of the different AR content is dependent of the distance from target, which is the distance from the camera to the given object in the test scene(could be the hole or the marker w/net). All the AR content described in this section is presented when the system algorithms are identifying the AR markers described in detail in the section *AR markers*.

Distance from target	AR content: Illustration	Description
Distance > 30 cm	Hole detected!	An alert indicating that a hole is detected on the net.

Figure 3.11: Configuration of "Hole detected!" alert.

At distances larger than 30 cm from target, if any holes are detected on the net, a large alert with the text *Hole detected!* is showing in a big, bold and red text. This alert makes it easy to located the hole and discover that a new hole have been detected. The main purpose of the alert is to make the support personnel aware that a new hole is detected. The text is in great contrast to the environments, ensuring great readability.

Figure 3.12: The "Hole detected!" alert presented during testing of the AR system. The indication is easy to discover, and have high readability.

In the distance range between 25 cm to 30 cm, an outline of the hole shows the location of the hole with associated size in the format of *width x height* in centimeters. The outline makes it easier for the personnel to visualize the hole, and get the size directly from the inspection of the net. The outline and associated size have the same configuration as in the *AR INFO* system. The difference in this system is that the outline color is changing

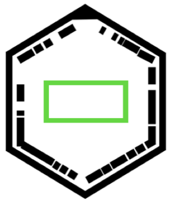
Distance from target	AR content: Illustration	Description
25 cm < Distance ≤ 30 cm		**Green:** Outline of hole w/size (width x height in centimeters).

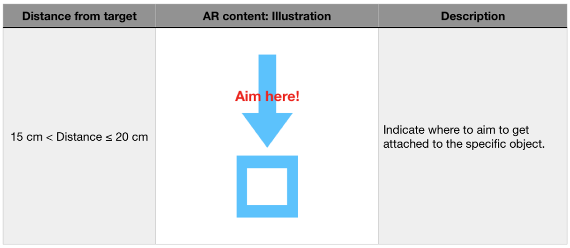
Figure 3.13: The configuration of the outline of hole with size indicator.

for each of the holes. In the experiment, markers(containing nets to fix the holes) have different colors that have to be matched with the color of the outline of the hole. At the test scene there are four holes, all with different colors on the outline. Further description is given in the chapter *Experiments and testing*. The bright colors of the outline, and text indicating the size, make it easy detecting and visualizing the hole.

Figure 3.14: The outline of hole with size during testing. The red outline indicates that a marker with net of color red have to be attached to fix the hole.

In the range between 15 cm and 20 cm from target, the ”Aim here!” text with associated arrow and location frame is shown. The AR content indicate where to attach the end of the stick in two different situations. The first situation, when the end of the stick is attached to the marker with net. The second situation is when the marker with the net is attached to the AR marker to fix the hole temporarily. The aim indicator is shown in light colors in great contrast to the environments, making it easy to know where to attach the end of the stick during the experiment. The text is written in bold and red color, ensuring great readability. This AR content is displayed using a regular AR square marker which is not a frame marker, and this marker is further described in the section *AR markers*.

At a distance range between 0 cm and 15 cm away from the target, a panel containing



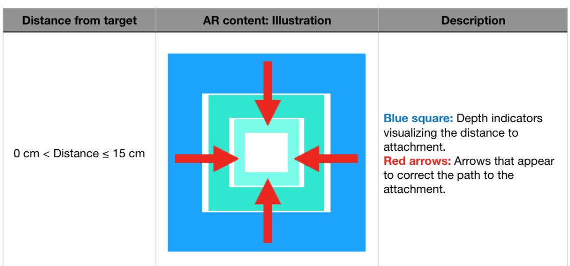
Distance from target	AR content: Illustration	Description
15 cm < Distance ≤ 20 cm	Aim here!	Indicate where to aim to get attached to the specific object.

Figure 3.15: The configuration of the ”Aim here!” indicator.

Figure 3.16: The ”Aim here!” indicator is shown both when the stick is attached to the marker with net(left), and when that marker is attached to the AR marker to fix the hole temporarily(right).

depth indicators illustrates how far the endpoint of the stick is away from the attachment. The panel is located some distance over the point where the attachment happens to hinder occlusion; that the endpoint of the stick is hidden behind the augmented depth indicators. The depth indicators work this way: When the endpoint of the stick is approaching the attachment, the square furthest out(blue) is disappearing when the distance to target is 10 cm or less. Then at a distance of 5 cm or less away from target the square in the middle disappears(dark turquoise). When the attachment is very close(0,5 cm - 1 cm away), the inner square disappears. This configuration makes it easier for the personnel to visualize the distance to target, and hence adjust the speed of the endpoint to the attachment accordingly. The depth indicators are made in bright colors, in great contrast to the environments.

If the path of the endpoint of the stick have to be corrected approaching the attachment,



Distance from target	AR content: Illustration	Description
0 cm < Distance ≤ 15 cm		Blue square: Depth indicators visualizing the distance to attachment. Red arrows: Arrows that appear to correct the path to the attachment.

Figure 3.17: The configuration of the depth indicators and correction arrows.

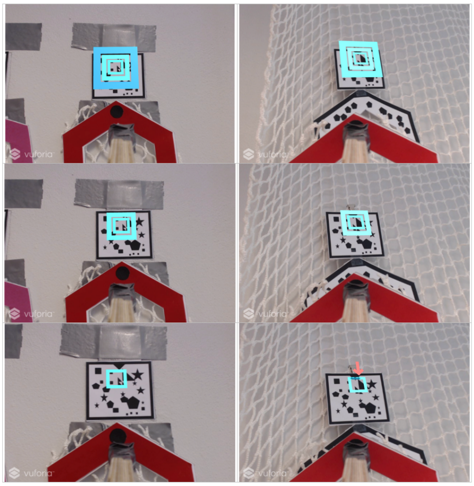


Figure 3.18: The depth indicators is appearing in two situations. The first situation, when the endpoint of stick is attached to the marker with net(left). The second situation, when the marker with net is attached to the AR frame marker to fix the net temporarily. The square of the depth indicator disappear approaching the target.

correction arrows are appearing on top of the depth indicators. The arrows indicate what direction the endpoint of the stick have to be moving towards to make a correct correction towards the attachment. If the endpoint of the stick have a deviation of more than 2 cm in any directions from the optimal path, correction arrows will appear pointing towards the correct direction to correct the path. If several adjustments have to be done, multiple arrows appear to indicate the necessary adjustments that have to be done. The depth indicators with associated correction arrows appear in two situations. The first situation is when the endpoint of the stick is attached to the marker with net. The second situation is when the marker with net is attached to the AR frame marker to fix the hole temporary.

Figure 3.19: If several adjustments have to be done, multiple correction arrows appear to correct the path.

3.3 AR markers

In this project, using marker-based AR, AR markers have been created and designed to display AR content. The markers have been created and designed using *Pages* for mac. The AR markers have then been uploaded to an online Vuforia database called the *Target manager*. In the database, each AR marker gets a rating from zero to five stars based on number of features for detection and the performance of the tracking of the marker. To use the AR markers in the project, the whole database of AR markers were downloaded to the Unity engine.

3.3.1 AR frame markers: Displaying AR content about the net holes

To display the AR content concerning the holes on the net, five AR frame markers have been designed. Frame markers are designed is such way that all the encoding to detect the marker is located on the outline of the marker. This created space in the middle of the marker where other real-world objects can be visualized, like holes on a fish cage net. At the Vuforia database all the AR markers or targets are measured in performance concerning target detection and tracking stability. All the AR frame markers have a rating of four or five stars, ensuring high performance in both target detection and tracking stability.

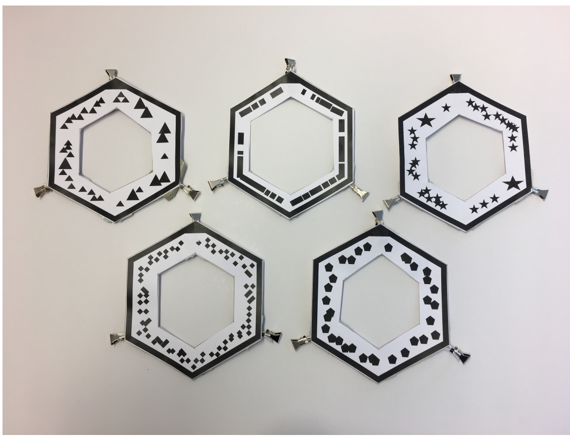


Figure 3.20: The five AR frame markers designed in the project.

The AR frame markers are designed in such way that the design follows the guidelines given from the official Vuforia developer portal, described in detail in the section *Characteristics of good AR markers* in the chapter *Background and theory*. The frame marker are rich in details, with encoding based on shapes with sharp edges creating many features and key points that ensure robust detection and tracking. The frame markers are created in colors black and white, creating good contrast between the different regions of the markers. With the encoding varying in both shape and size, no repetitive patterns can be found on the marker. This is important to find the correct pose of the marker, and hence displaying the associated AR content with the correct pose and scale.

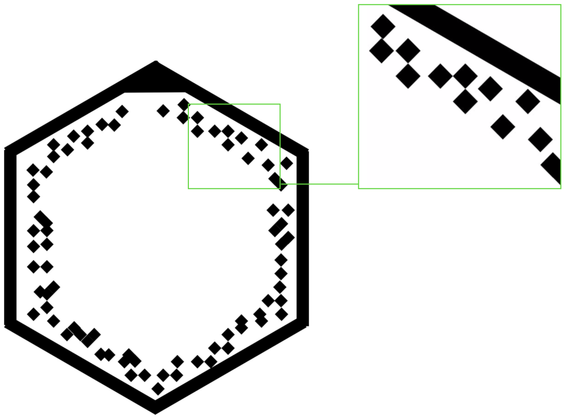


Figure 3.21: The encoding of the marker used to detect the AR marker. The encoding follow the guideline of design given by the official Vuforia guide[18].

The size of the markers is 19.8 cm x 17.7 cm(height x width). The size is suitable at the distance ranges in the experiments, making the markers suitable displaying AR content at both small and large distances from target. The markers are printed on regular paper, ensuring no glossiness. Cardboard have been used to make the markers more robust, and ensure flatness. To attach the markers to the net, clips have been used.

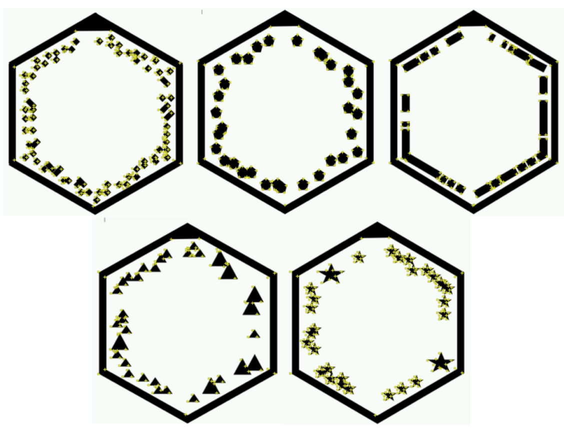


Figure 3.22: The AR frame markers are rich in details and features, ensuring robust detection and tracking. The *Image is take directly from the Vuforia developer portal, all rights belong to Vuforia[2]*

3.3.2 AR square marker: Displaying AR content concerning positioning support

To display the AR content related to the positioning support of the stick, an AR square marker was designed. The square marker have the same configuration as a regular QR-code, with encoding over the whole marker. The square marker have a rating of five stars, ensuring excellent performance in marker identification and tracking.

Figure 3.23: The AR square marker created and designed in the project.

The square markers design follows the guidelines given under the section *Characteristics of good AR markers* in the *Background and theory* chapter. The square marker is rich in details, since the encoding have a basis of many different shapes with sharp edges. This creates many features and key points that make it easy to identify and track the marker. Since the marker is made in the colors black and white, high contrast is ensured between the regions of the marker. With the different kinds of shapes, with different orientations and sizes, no repetitive patterns is present in the marker. Hence, obtaining the correct pose is ensured. This is especially important for this marker, since the AR content must be accurate and precise to achieve optimal positioning support during the interaction operation.

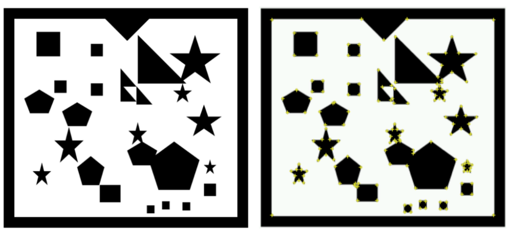


Figure 3.24: The AR square marker(left). The feature and key points of the AR square marker(right). *The image to the right is taken directly from the Vuforia developer portal, all rights belong to Vuforia[2]*

The size of the square marker is 8.0 cm x 8.9 cm (Height x width). The square marker is smaller than the frame marker, since the AR content displayed using this marker will happen at lower distances closer to the net. The size ensures robust displaying of AR content at suitable distances. The marker is printed on regular paper, ensuring that the marker is not glossy. Glossiness could cause problems in sharp light conditions. To make the marker more robust, cardboard have been added at the back of the marker. This also ensures flatness, so that the features and key points are not hidden caused if the marker is bulging. Clips are used to attach the marker to the net.

Chapter 4

Experiments and testing

To test the AR systems described in the section *Design and implementation*, two experiments have been conducted. In these experiments the test persons have been completing similar tasks with the AR systems and traditional systems with no AR. All mentions of a *traditional system* in the following sections, means that the system does not contain any AR, and is only a regular video feed from the operation.

Five test persons completed the experiments, where all of the test persons were in the age range of 23-25 years old. In the following sections, the experiment setup and the two experiments are described in detail. Important measurements are also given, if someone wants to create a similar experiment or do further testing on the topic in the future.

4.1 Experiment setup

A test room was use to setup the experiment. To conduct the experiment, the test person comes into the room, get the necessary information to get started and then starts doing the experiments. The experiment setup contain of the following parts:

- **Workstation**: The table containing the pc and other necessary documents to conduct the experiments.
- **Test wall**: The wall hiding the test scene from the test person.
- **Stick with camera**: The stick that the test person operate to do the inspection of the net in the experiment. A live video feed is sent from the camera to the computer at the workstation.
- **Test scene**: The scene that have to been inspected during the experiments. The test scene contain original fish cage nets, AR markers and other components used to complete the tasks in the experiments.

The workstation is the first part of the test setup that meets the test person. During testing, the test person is standing beside the workstation, solving the tasks that the specific experiment contain. The work station contain a computer that gives the live video feed from the inspection of the test scene. In the INFO experiment a Google Form with tasks is also part of the computer screen. The configuration of the computer screen of the INFO experiment will be described in detail in the section *INFO experiment*.

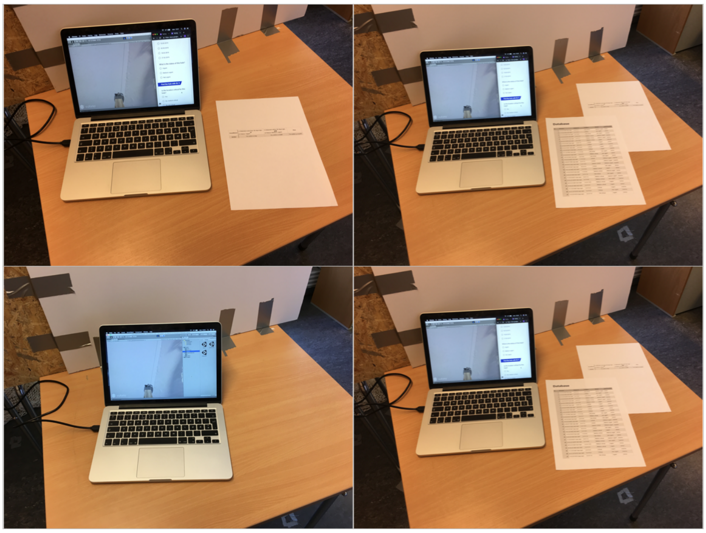


Figure 4.1: The workstation have different configurations, dependent on which part of the experiments being completed.

The workstation does also contain necessary documents needed to complete the experiments and pen and paper if the test person feel the need to take notes to complete the tasks. The different configurations of the workstation are dependent on which part of the experiment that is conducted. In the case where the traditional system is tested, documents with relevant information are added to the workstation to compensate for no AR info from the net. The reason for the added documents, is to have a better basis for comparison between the AR system and the traditional system. The different configurations of the workstation will be explained in detail in later sections.

During the experiments, the test person is standing behind a test wall hiding the test scene where the inspection happens. The reason for using a test wall, instead of doing inspection by looking at the test scene, the test person must access and view the inspection through a video feed from a camera. This is a more realistic and similar approach when compared to drone operations done in aquaculture. The test wall is large, hiding the whole test scene with a good margin. The test wall is standing on top of three tables with the same height as the table of the work station(74 cm). The material used to build the test wall, is a OSB plate in the middle, and heavier cardboard plates at the sides and top of

Figure 4.2: In front of the test wall(left) with the workstation in the front. Behind the test wall(right) with the stick, with a camera attached, placed in the docking.

the test wall, to ensure that the test wall is big enough to cover the whole test scene. The cardboard plates on the side are reaching all the way up to the ceiling of the test room.

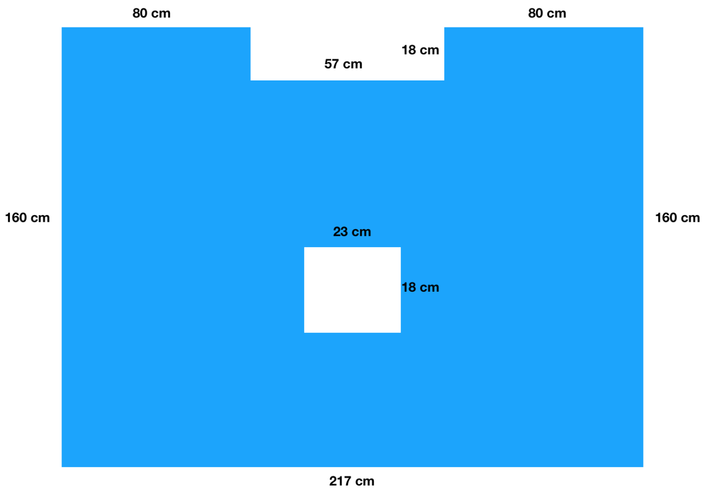


Figure 4.3: The measurements of the test wall with the opening in the middle.

To stabilize the test wall, the OSB plate is attached to a heavier plywood plate laying on the table holding the test wall up. In the middle of the OSB plate is a hole, where the stick with camera is attached. Seeing through this hole, the test person can see the test scene, but this is not allowed during the experiments. The only time the test person is allowed to peek through this hole, is when the stick with camera is attached to the docking(to ensure that the docking is not destroyed while docking the stick). When the test person is standing, the hole cannot be seen through since the hole is placed at the lower part of the test wall. Hence, the test person cannot peek directly through the hole at any time. Thinner cardboard paper have been used to make the hole in a more suitable size; small enough to not see any of the test scene, but large enough to manoeuvre the stick with the camera in an easy way. The measures of the hole in the test wall is 18 cm x 23 cm(height x width).

To get the live video feed from the operation done on the net, the test person operates a stick with a web camera of the type *Logitech Webcam C925e* attached at the end of the stick. The camera is placed in two different position, dependent on which of the two experiments that are being completed. The end configuration of the stick is further explained under the sections describing the experiments. To attach the web camera to the computer, a USB extender have been used to ensure that the stick can be moved in such way that the whole test scene is accesses in a secure way without losing connection of the video feed. The stick have a length of 172 cm, with a width of 1.7 cm and height of 2.3 cm. The stick is attached at the hole of the test wall.

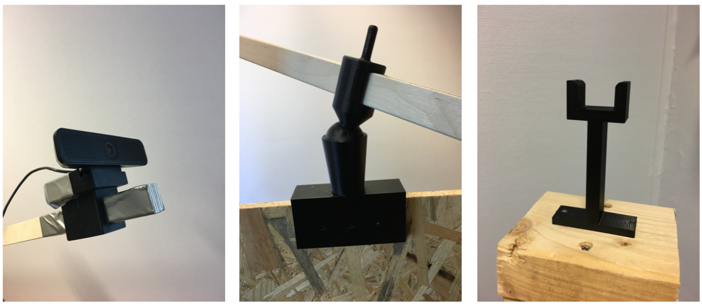


Figure 4.4: The 3D printed objects. The attachment between the camera and stick(left). Attachment between stick and test wall(middle). The docking of the stick(right).

When creating the setup to the project, three objects have been designed using the CAD program *Creo Parametrics* and 3D-printed. The stick is attached to the test wall using a 3D-printed attachment. The attachment is made as a sphere joint, and the stick is not locked in the attachment. Then the stick can be moved freely, suitable reaching the entire test scene. The attachment contain of two parts: The first part is the attachment to the test wall with a placeholder for the sphere. The other part contain the sphere and the attachment of the stick. To connect the two parts, the sphere is ”clicked” into the placeholder of the other part. Multiple prototypes were tested to check the tolerance between the sphere and the placeholder, ensuring that the stick were comfortable moving during the experiments. The attachment between the camera and the stick was also designed and 3D-printed. The attachment is made in such way that the placement of the camera on the stick can easily be changed in between different experiments. The attachment with the camera slides freely on the stick, and can be fasten easily with tape. The last object designed and 3D-printed, was the docking of the stick. The docking was designed so that the test person had a location to easily dock the stick under and after the experiments.

The test scene is the area that have to be inspected by the test person during testing.

Figure 4.5: The plain test scenes with only the fish cage nets with holes. During testing, additionally AR markers and other components will be part of the test scenes. The plain test scene of the INFO experiment(left), and the plain test scene of the INTERACTION experiment(right) are shown.

The test scene is hidden behind the test wall, and the only way the test person can access and see something from the test scene, is through the video feed from the camera attached to the stick. The distance between the test wall and the test scene is 112.5 cm. Real-world inspections are happening in less than two meters away from target(caused of the foggy and unclear water), so the distance between the test wall and test scene is both realistic and comparable to real-world operations. The measures of the whole available space for testing in the test scene is 150 cm x 200 cm (height x width). Each experiment have several different test scenes, which are changed throughout the completion of the different experiments. The different configurations of the test scenes will be explained in detail in the sections describing the experiments below.

4.2 INFO experiment

In the INFO experiment the five test persons are going through a similar set of tasks using an AR system and a traditional system. The test persons will do inspection on different test scenes, where one test scene is inspected with AR, and the other is without AR. In both cases the test person is solving a similar set of different tasks to evaluate how the different systems performs. To make the test persons familiar with dynamics of the hardware and software, the first test scene is used for familiarization of the system.

The purpose of this experiment is first and foremost to see how well the AR system achieves different tasks compared to the traditional system. Further, the experiment will test if AR could provide faster determination of actions, and if added AR info provide greater overview during ROV operations. The results will also give a basis on the discussion if AR could save time, reduce cost, achieve better information flow and give added decision support. The user interface and usability of the AR system will also be compared to the traditional system.

4.2.1 Description

The scenario of the experiment is that the control personnel at an aquaculture site have conducted a net inspection and have detected five holes on the net. The test persons task is to gather important information of the holes detected, and use this information to solve a set of tasks, answering questions about the holes and determine when the holes have to be fixed. The scenario is tested both with the AR system, using the AR INFO system described in the chapter *Design and implementation*, and a traditional system.

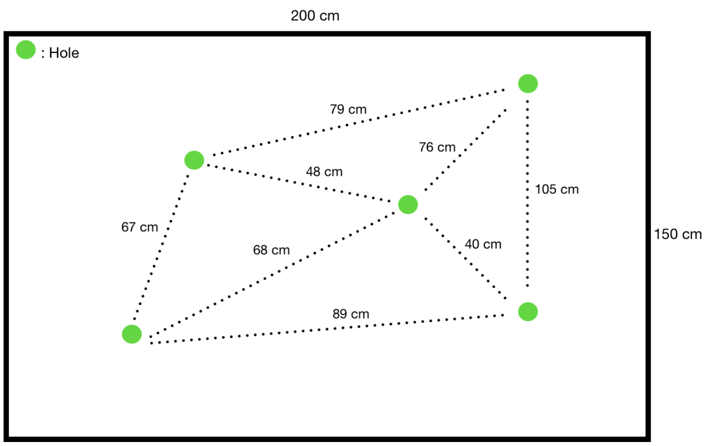


Figure 4.6: The configuration of the test scene with distances between the holes.

In the scenario where the AR system is used, AR markers have been placed on the holes, and all the info is given from the AR system. In the case where the system with no AR is used, the test person must find the ID of the hole by doing an inspection of the net, and then find the associated information from a document working as a database. The different questions related to the set of tasks, are answered through different multiple choice questions in a Google Form. The Google Form is a part of the computer screen, in addition to the live video feed from the inspection. Before the experiment, the test person have been given all the necessary information of the AR system and experiment.

4.2.2 Test procedure

The experiment is divided into three different parts, with associated test scenes. Each segment of the experiment is described in detail in the following sections.

Part one: Familiarization of the system

In the first part of the experiment the test person gets familiar with the software of the system and the hardware of the test setup. The test person gets used to getting the info from the video feed and the dynamics of the stick with the camera among other things. The test scene contain of five indicators in a bright red color with a number in black indicating the number of holes. The indicators are placed where the five detected holes are located, and the test person then knows where the different holes are located before part two and three, when the AR system and traditional system are tested.

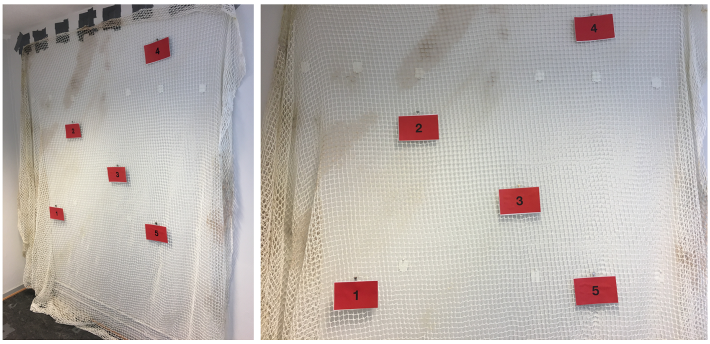


Figure 4.7: The test scene in the familiarization part of the experiment.

The reason that the test person gets to know the location of the holes at such an early stage of the experiment, is that there should not be an advantages in knowing where the holes are between the trailing parts following the familiarization part. This makes a more fair comparison, and the focus of the experiment is not to located the holes, but on the information gathering and use, to solve different types of tasks with or without AR. The red indicators have a measure of 10.6 cm x 17.0 cm(height x width). The indicators are attached to the net using clips, for fast attaching and detaching of the indicators in between the different parts of testing. The test person get enough time to get familiar with the system and to become secure on how to operate both the software of the system and the hardware of the experiment setup. The test person does not have to answer or complete any set of tasks at this part of the experiment.

Part two: Testing of the traditional system

In part two of the experiment the performance of the traditional system without AR is tested. The traditional system does only contain a regular video feed from the inspection without any AR information. The system is comparable to video feeds of drone operations done at the aquaculture today, where no AR content is showing. Additional information from the video feed in drone operation in aquaculture today may contain of some UI components, displaying the depth, heading angle and time and date. Hence, the traditional system tested in this part of the experiment is highly comparable to video feed from drone operations done in the aquaculture today.

In this scenario, the support personnel have attached IDs to the five holes detected. The test person have to find important information about the holes to solve the set of tasks presented in the Google Form showing on the computer screen. The associated information of

Figure 4.8: The test scene in the part where the traditional system is tested.

each hole is found by, firstly, finding the ID of the specific hole by doing an inspection on the net. Then, secondly, use the ID of the hole to find associated information in a look-up table serving as a database. The look-up table /database is a document at the workstation, and is presented in Appendix C. The measures of each ID is 9.1 cm x 9.0 cm(height x width), and is attached to the net using clips.

The structured set of tasks is divided into three different parts to test different ways of inspecting the net and holes. The first part of the tasks is a one-on-one inspection of the net holes, with some comparison tasks in the end of the part. The second part contain overall inspection, doing inspection of all the detected holes on the net. The last part, the test person have to match the information gathered towards a framework, to determine how many holes that have to be fixed in a specific time. The structured set of tasks are presented below:

1. Select the *NoARsystem* scene on the screen of the computer in the Unity editor.
2. Start the test by navigating the camera with the stick.
3. **Inspection of specific holes**
   (a) Find the hole with ID: 7.
      i. When was this hole detected?
      ii. What is the status of this hole?
   (a) Find the hole with ID: 12.
      i. Is the location critical for this hole?
      ii. What is the size of this hole?
   (a) Find the hole with ID: 19.
      i. Is this hole more urgent to fix than the hole with ID: 7?
      ii. Is this hole larger than the hole with ID: 12?

4. **Overall inspection**
   (a) How many holes have a width of 7 cm or more? (Hole size: Width x Height)
   (b) How many holes have the status ”Urgent”?
   (c) Which hole was detected first? Which date was it detected?

5. **Determining action using a framework**
   (a) Use the framework in figure 1, and answer the following questions:
      i. How many holes should be fixed within a day?
      ii. How many holes should be fixed withing a week?
      iii. How many holes should be fixed withing a month?

Conditions	1) Detected more than 30 days ago. **or** 2) Status: Urgent	1) Detected within 30 days ago. **and** 2) Status: Medium urgent	Else
Action	Fix within a day	Fix within a week	Fix within a month

Figure 4.9: The framework used to determine how many holes that should be fixed within a specific time. This is the framework in *figure 1* that the set of tasks refer to. This framework is used in both part two and part three of the test procedure.

Part three: Testing of the AR INFO system

Part three of the experiment concerns testing the AR INFO system, described in detail in the section *AR INFO system* in the chapter *Design and implementation*. All the information about the holes detected are given as AR content from the AR INFO system. In the scenario where AR is used, the control personnel have placed AR frame markers around the five holes detected. These are the five AR frame markers described in detail in the section *AR markers* in the chapter *Design and implementation*. The different holes are located in the middle of the AR frame marker, and when the marker is detected, all necessary AR info is displayed.

To find the necessary information about the holes to solve the set of tasks, the test person uses the AR system to find the correct hole with the correct ID doing inspections on the net. When the hole with the correct ID is found, the test person approach this hole to gather the necessary information to complete the set of tasks. The set of tasks is answered in a Google Form, in the same way as in part two of the test procedure. Hence, all the info during testing is given from the AR, and no need for a database or look-up table is present.

The structured set of tasks and the associated framework on the last part of the set, is almost the same as in part two of the test procedure. The only difference is that the IDs of the different holes that must be inspected in the *Inspection of specific holes*, are changed to

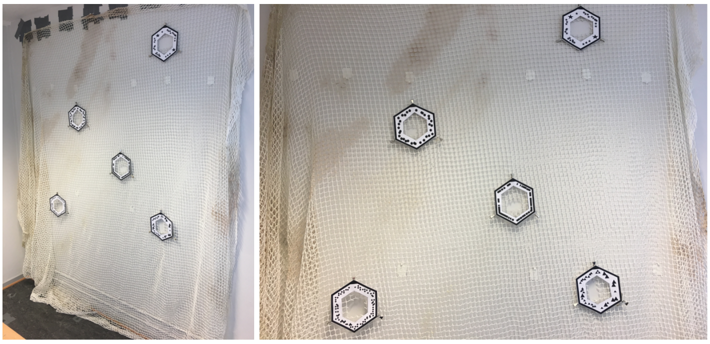


Figure 4.10: The test scene used to test the AR INFO system.

other values. With the different types of questions in the set of tasks, ranging from one-on-one inspection to overall inspection, and then determining actions based on a framework, a wide variety of different types of information gathering are tested. The experiment will evaluate how the AR INFO system performs in completing these different tasks compared to the traditional system. The structured set of tasks are presented below:

1. Select the *ARinfo* scene on the screen of the computer in the Unity editor.
2. Start the test by navigating the camera with the stick.
3. **Inspection of specific holes**
   (a) Find the hole with ID: 15.
      i. When was this hole detected?
      ii. What is the status of this hole?
   (a) Find the hole with ID: 9.
      i. Is the location critical for this hole?
      ii. What is the size of this hole?
   (a) Find the hole with ID: 11.
      i. Is this hole more urgent to fix than the hole with ID: 15?
      ii. Is this hole larger than the hole with ID: 9?
4. **Overall inspection**
   (a) How many holes have a width of 7 cm or more? (Hole size: Width x Height)
   (b) How many holes have the status ”Urgent”?
   (c) Which hole was detected first? Which date was it detected?
5. **Determining action using a framework**
   (a) Use the framework in figure 1, and answer the following questions:

i. How many holes should be fixed within a day?
ii. How many holes should be fixed withing a week?
iii. How many holes should be fixed withing a month?

4.2.3 Assumptions and limitations

In this experiment there are several assumptions and limitations. The experiment is done over water, but the AR systems used in the tests are intended to be used in underwater drone operations. The reason the systems are tested over water is a combination of different reasons. Related to the AR, it is easier to test over water, since the conditions related to turbidity and light conditions make the testing quite hard. The Vuforia engine is not tested sufficiently for underwater operations, resulting in an AR system that is not robust underwater. In this experiment, the main focus is on the usability and user interface in information gathering, and dealing with different kinds of information, not the robustness of the system underwater. Testing over water, ensures that the AR system is working well, and a thoroughly evaluation of the system can be achieved. The traditional system, which is a regular video feed, would work optimal underwater. The AR system could potentially break down underwater caused by the conditions discussed in the section 2.4.2. To make a fair comparison between the AR system and the traditional system, the testing was chosen to be done over water.

Marker-based AR have been used as the method to display AR content in this experiment. Using markers is the easy way to display AR content, and marker-based AR have been chosen as the method to display AR, so that a large, complete AR system could be made on the restricted time frame of the project. In the future, the ultimate goal is that markerless AR is used in drone operations, using a combination of computer vision and external sensors, like gyroscopes, GPS and accelerators. Implementing a markerless AR system is a more complex task, and the implementation would have been limited cause of the time frame of the project. Again, the focus of the project is the usability and user interface, and comparing the AR system to more traditional methods used in drone operation in aquaculture. Using markers fulfill this purpose in a sufficient way.

Since the markers and IDs have been placed on the net, before the test person begin the inspection, the assumption is that support personnel have been there already with a drone and placed different types of markers and IDs to indicate the holes. In reality, this is not a realistic way to do the operation. In reality, the operation is done in two stages, the first is detection, the second is repair. In the scenario shown in the experiment, the operation will be divided into three parts, creating a three-stage process. The first stage, the support personnel detect the holes. The second part, the test person investigate the holes. And the last part, the holes must be repaired, based on the information gathered by the test person in the second part of the operation. The extra step of the operation will not be realistic, and is not desired, since it will cause increased cost of the operation. The scenario was made this way, because the focus is on the information gathering, and how to work with this information, and not reduction of cost or repairing the holes. The scenario made, accomplishes to show a lot of different information from the AR system, that still

could be used in more realistic scenarios.
To operate the camera, a stick was used instead of a drone. The movement of the stick is not exactly the same as the movement of a drone. A stick was chosen, since it was easy to setup, and the movement is sufficient enough to make a fair comparison to the movement of a drone. In this project, how the camera moves is not important, as long as it is comfortable for the test person using the system and doing the completion of the set of tasks. To test the AR system thoroughly, many holes are located in a small area of the net. To have so many holes in such small area of the fish cage net is not realistic. The decision was made, based on the space available, and to ensure sufficient testing of the systems. When testing the traditional system, a database is used. In real-world operations the use of look-up tables and databases is limited. The database/look-up table is used to create a scenario with the traditional system, that is comparable to the scenario with the AR system.

4.2.4 Evaluation

To analyze the performance, usability and user interface of the AR system and traditional system, several evaluations have been completed under and after the experiments. The different evaluations conducted, are described in detail in the following sections.

NASA-TLX app

After part two(testing of the traditional system) and part three(testing of the AR INFO system), the test person is going through an evaluation of the two systems in the NASA-TLX app. The evaluation process of the NASA-TLX app is described in detail in the section *Workload* in the chapter *Background and theory*. The evaluation is testing the overall workload of the systems, analyzing six different categories contributing to the workload: Mental demand, physical demand, temporal demand, performance, effort and frustration. Scores on each category and the overall score for each test person, with analysis, can be found in the *Results* chapter.

Screen recording

Screen recording is done in part two(testing of the traditional system) and part three(testing of the AR INFO system) of the experiment. The screen recording have been analyzed after the experiment is finished. Completion times of the different parts of the set of tasks, and important observations and analysis of the screen recording can be found in the *Results* chapter.

Objective observation

During testing, objective observations have been conducted. The objective observations contain comments from the test person during testing, observations on how the test person operates the system and if anything surprising happens during testing among other things. The observations have been written down during testing, to create a basis for discussion.

Subjective evaluation

The test persons evaluate both the AR system and traditional system through a subjective evaluation completed after the experiment. Google Forms is used to create the evaluation form. The evaluation is sent by mail to the test person, and completed shortly after the experiment. In the evaluation, different usability goals are evaluated, described in detail in the section called *Usability goal* found in chapter 2. The evaluation contain of multiple-choice questions, scale questions and questions where the test person must give a comment. In the range questions, the test person is asked to set a value in a range from 1 to 5, on what the degree the test person agrees, how helpful a certain part was or how much a part of the system enhanced the operation among other thing. Examples of some of the ranges of answers to choose from is shown below.

Strongly disagree - Disagree -Neutral - Agree - Strongly agree
Very unhelpful - Unhelpful - Neutral - Helpful - Very helpful
Very difficult - Difficult - Neutral - Easy - Very easy

The data and results from the evaluation form a basis for analysis and discussion of the performance in the different categories. The analysis and discussion can be found in the *Results* chapter. The entire subjective evaluation of the INFO experiment can be found in Appendix B.1.

4.3 INTERACTION experiment

In the INTERACTION experiment, the five test persons will do an interaction task on different test scenes, one with the AR system and the other with the traditional system. The interaction task is to detect a hole in the net, and then attach a net over the hole to fix the hole temporary until the hole can be fixed permanently. The AR system used in this experiment is the AR INTERACTION system, explained in detail in the section *AR INTERACTION system* in the chapter *Design and implementation*. The test procedure and task to be done is the same both with and without AR, but in the AR case the positioning of the stick is supported by added AR content. Also added AR content related to identification and inspection of the hole is added.

An interaction operation is an operation where the drone is interacting directly on the net or mooring, like in repair and maintenance operations where the net is fixed or cleaned. The purpose of the experiment, is to test if AR could be helping in navigating the drone during repair operations of the net. The experiment will test how confident, fast and accurate the test person operates and complete the tasks with the AR system, compared to the traditional system. The user interface and usability of the AR system compared to the traditional system will also be evaluated. Necessary information about the AR system and the experiment in general is given to the test persons before the experiment.

4.3.1 Description

The scenario in this experiment, is that a drone is doing an inspection and repair operation on the fish cage net. If any holes are detected, these holes must be temporary fixed so that no fish escapes until the holes are fixed permanently. The inspection is done by operating the stick and getting the video feed from the camera on the computer at the workstation. The test persons task is to find the different holes in the test scene, and fix these holes using a marker with a net attached. In the test scene there are four holes that have to be fixed, and each hole must be fixed with a specific marker with net, dependent on the size of the hole. The exact procedure that have to be done by the test person is given below:

1. The test person detects the hole.
2. The test person finds the color of outline displayed on the hole, and the size of the hole.
3. The test person finds the marker with the color matching the color on the outline of the hole. This marker have a net attached to it, to fix the hole temporary.
4. The test person achieves the goal of the operation by attaching the marker w/net to the AR marker on the hole to fix the net temporary until the net can be fixed permanently.

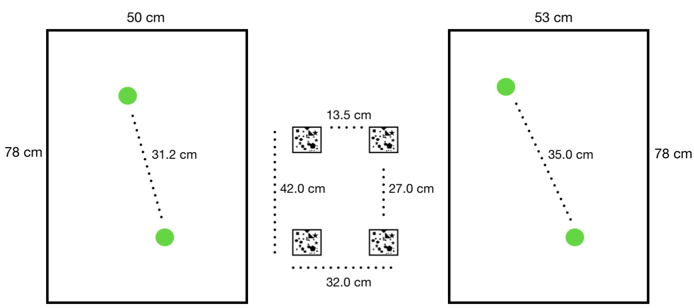


Figure 4.11: The configuration of the test scene with distances between holes and AR markers.

In the AR case, the AR INTERACTION system, described in the section *AR INTERACTION system* in chapter *Design and implementation* is used. All the necessary information the test person need during the AR part of the experiment is supplied by the AR system. To fix the holes, the hole detected must be fixed with the marker with net of the correct color code. The procedure of matching the correct marker w/net to the correct hole detected, will be explained further in the sections below. In the part where the traditional system is tested, the test persons must found the ID attached to the different holes in the test scene, and find the associated marker w/net using a framework at the workstation.

In the test scene, there are four holes that have to be fixed by the test person. The test person find these holes, and then try to fix them using a marker w/net. Magnets are used

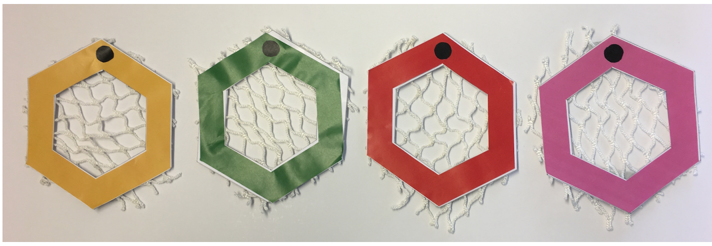


Figure 4.12: The markers w/net created to fix the holes temporarily.

to attach the marker with net to the stick, and further to attach the marker w/net to the AR marker framing the hole, to fix the hole temporary. In this experiment, the end configuration of the stick used to operate the camera, have a magnet attached at the end. The magnet enable the stick to pick up the marker w/net. Both the marker w/net and the AR frame markers at the net have magnets attached at the back, to ensure that an attachment can be made. The camera is placed 25.5 cm away from the end of the stick, to ensure better overview of the operation, and that the end of the stick is showing during operation.

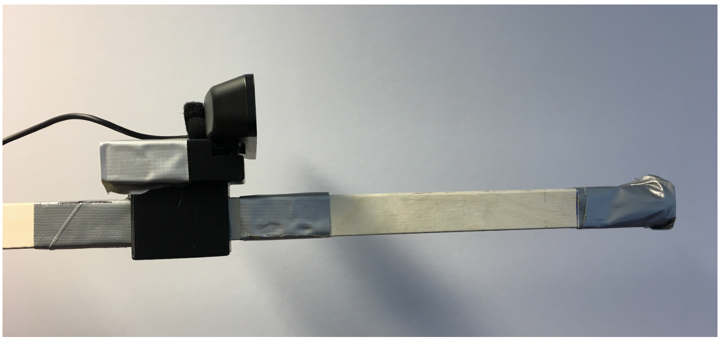


Figure 4.13: The end configuration of the stick. A magnet is attached at the end of the stick, and the camera is placed 25.5 cm away from the end of the stick.

4.3.2 Test procedure

The experiment is divided into two different parts, with associated test scenes. Each part is described in detail in the following sections.

Part one: Testing the traditional system

In the first part of the test procedure, the traditional system is tested and evaluated. The traditional system does not contain any AR, and is only a regular video feed from the camera during inspection. In the test scene, IDs have been attached to the holes that have to be detected. The test person find the ID of the hole by doing an inspection on the net. Further, the marker w/net with the correct color, in the middle of the test scene, is found using info and a framework on a paper at the workstation. This procedure is done for all of the four holes, and the total time completing the task is gathered through screen recordings of the computer screen during the testing.

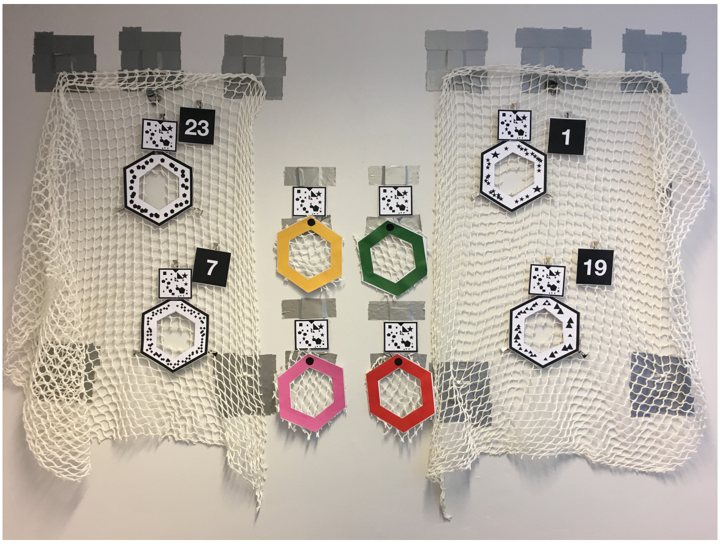


Figure 4.14: The test scene used to test the traditional system. The different IDs have been placed at the holes. The markers w/net are in the middle of the test scene. These markers w/net are attached to the AR frame markers framing the net holes during testing.

An example of the matching procedure is shown below:

1. The test person finds the hole with ID: 12, through an inspection of the net.
2. The test person looks up the size of the hole(11.3 cm x 5.5 cm) using the info paper at the workstation.
3. Using the info about the hole, the test person finds the area of the hole(62.15 cm(̂2)) using the info paper at the workstation.
4. The color of the marker w/net(green) is found through a framework on the paper at the workstation.
5. Then, the test person find the marker w/net with the correct color in the test scene, and attach the stick to this marker.
6. The marker w/net with the correct color is attached to the AR marker framing the hole to fix the hole temporarily.

This procedure is done for each of the holes in the test scene.

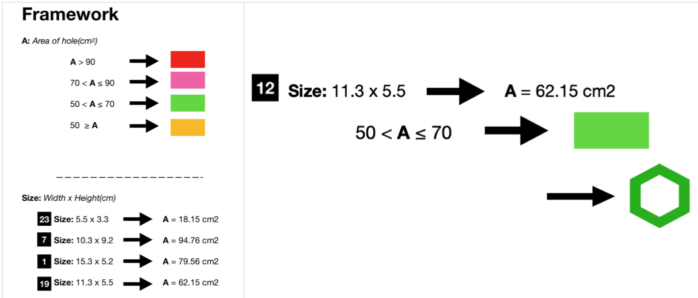


Figure 4.15: The framework and info to determine the color of the marker w/net to fix the specific hole(left). The information flow to determine the color of the marker w/net(right).

Part two: Testing the AR INTERACTION system

In the second part of the experiment, the AR INTERACTION system is used and tested, described in detail in the section *AR INTERACTION system* in the chapter *Design and implementation*. All the information needed to determine the marker w/net with the correct color is given from the AR system. The AR frame markers display the information necessary during detection and inspection of the holes. The AR square marker is used to display information adding positioning support to the test person while testing. Both the AR frame markers and the AR square marker used in this experiment is explained in detail in the section *AR markers* in the chapter *Design and implementation*.

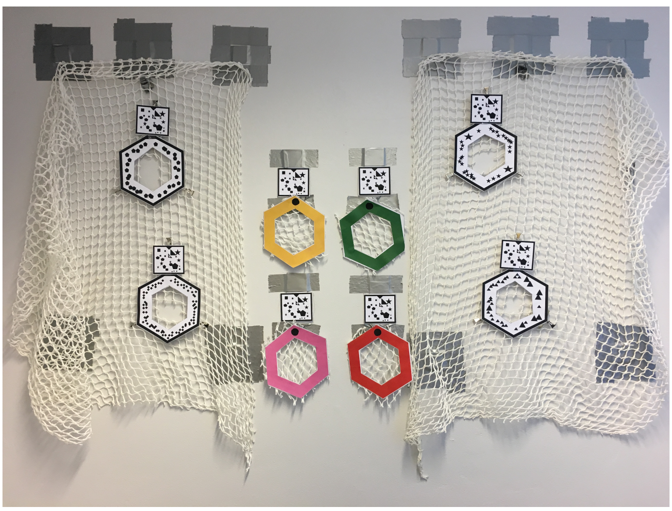


Figure 4.16: The test scene used to test the AR INTERACTION system. The AR frame markers framing the holes give the necessary information when detecting and investigating the holes. The AR square markers display positioning support for the stick when detected by the AR system.

The procedure of fixing the hole using the AR INTERACTION system is described below:

1. First, the test person detects the hole in the test scene. A large augmented alert with *"Hole detected!"* is showing at the location of the hole.
2. Approaching the hole, the augmented outline of the hole is showing. The color of the outline have the same color as the associated marker w/net that fixes the hole.
3. The test person find the associated marker w/net, with the same color of the outline at the hole, in the middle of the test scene.
4. The associated marker w/net is attached to the AR frame marker framing the specific hole, to fix the hole temporarily.

This procedure is done for each of the four holes in the test scene, and the completion time of the fixing of the four holes is gathered through screen recording of the computer screen during testing.

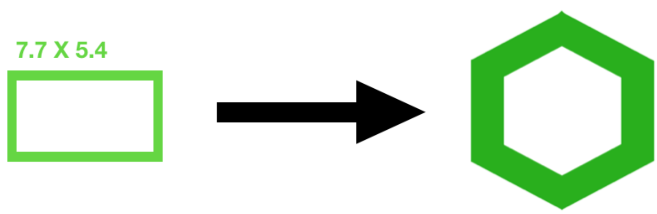


Figure 4.17: The color of the augmented outline with size of the hole is indicating the color of the associated marker with net to fix the detected hole.

4.3.3 Assumptions and limitations

The experiment is conducted over water, despite being intended for underwater operation. Testing AR systems under water is quite challenging. Different light condition and turbidity among other things, make it hard to make a complete testing of the AR system. The focus of this experiment is not to test how robust the AR system is, but to get an idea on how AR can be used in interaction operations underwater. Hence, the testing is chosen to be done over water, since that will make a fair comparison between the AR system and the traditional system. A natural cause of the testing over water, is that the camera is not attached to a drone, but a stick. This choice made it easier to create a complete experiment setup in the time frame of the project.

To display the information, AR markers were used in a marker-based AR approach. In real-world operations, markerless AR using computer vision and external sensors will be used, and no markers will be seen during operation. The reason markers are used, is to easier display AR content of the AR system, and to make a more complete AR system for testing. Creating a markerless AR system is more complex. Given the time frame of the project, the implementation of a markerless AR system could have resulted in a smaller, less complete AR system. To attach the markers to the stick, and to the AR marker fixing the hole, magnets are used. Using magnets to fix a hole on the fish cage net is not realistic. To interact with the different objects in the test scene, using magnets was a convenient way to do the interaction. The main focus in the experiment is to show how the AR could help in an interaction operation, and not on the interaction between the objects themselves in the scene.

In the case where no AR were used(traditional system), IDs were already placed on the holes of the net. The assumption is that the test person find the ID at the same time as the hole is detected for the first time. This is not realistic, since someone must have been there placing the ID before detecting it! Placing the IDs make it possible for the test person to look up the size of the hole, making the scenario more comparable to the part where AR is used. The reason the size of the holes are already determined on the paper at the workstation, is to make the no AR scenario more comparable to the AR scenario, where the size is displayed right away. If the test person uses a lot of time determining the size of the hole, this could lead to very variable results dependent on how determent the test person is. Having the size of the hole determined beforehand, makes the testing more controlled, and the results more comparable between the two systems. Here, the focus is not to find out how fast the test person can determine the size of the hole, but to measure the performance of the interaction of the different objects in the test scene of the two systems.

4.3.4 Evaluation

Several different types of evaluations and analyzes have been conducted to test the performance, usability and user interface of the AR INTERACTION system and the traditional system. Evaluations have been completed during the testing, and after the testing. All the evaluations are described in detail in the following sections.

NASA-TLX app

After both parts of the test procedure, the test person was going through a detailed evaluation of the workload of the tasks completed in the experiment, using the NASA-TLX app. Six factors are contributing to the overall workload, including mental demand, physical demand, temporal demand, performance, effort and frustration. What the different factors entail, and the procedure of the evaluation, are described in detail in the section *Workload* in the chapter *Background and theory*. The scores of each category and the overall score to each test person can be found in the chapter *Results*.

Screen recording

The video feed of both parts of the test procedure are screen recorded. The recording is further analyzed and important observations are discussed in the *Results* chapter. The completion time with AR and without AR is a metric that also is presented and discussed in the *Results* chapter.

Objective observation

During the experiment, objective observations have been conducted. The main focus have been on how the test person operates the system, comments from the test person and if anything surprising is happening during testing. The observations are a basis for discussion, getting direct input from the test person while the systems are tested. Important observations are presented in the *Results* chapter.

Subjective evaluation

After the experiment, the AR INTERACTION system and the traditional system are evaluated by the test person in a subjective evaluation. The evaluation was created and completed by the test person in Google Forms. The evaluation was sent to the test person by mail, and completed shortly after the experiment was finished. The subjective evaluation in this experiment have almost the same configuration as the subjective evaluation of the INFO experiment. The only difference are some adjustments of the questions in the comparison of the AR system and traditional system, and different questions related to the AR components of the AR INTERACTION system. The different questions are based on evaluating the different usability goals, described in the section *Usability goals* in the *Background and theory* chapter. The evaluation contains scale questions, multiple-choice questions and comments from the test person.

The performance, usability and efficiency of the AR system, compared to the traditional system, are evaluated and forms a basis for further discussion and analysis in the *Results* chapter. The entire subjective evaluation of the INTERACTION experiment can be found in Appendix B.2.

Chapter 5

Results

In this chapter, the results from both the INFO and INTERACTION experiment are presented. The first sections look into the results from the INFO experiments, and then the the results from the INTERACTION experiment are presented. In the end, a proposal of an improved AR system, based on the evaluation of the two AR systems implemented, are presented. All the results presented in this chapter are discussed consecutively. This way, the reader have an easier time following the discussion with associated results. The discussion is written in *italic* so that the reader have an easier time separating the presenting of results and the discussion conducted.

5.1 Results of the INFO experiment

The next sections will present the results from the INFO experiment. Results include completion times of tasks, data from the subjective evaluation and measures of workload through the NASA-TLX app. Objective observations of relevance are also discussed and analyzed. All results are discussed consecutively.

5.1.1 Completion times of tasks

In this section, completion times of the INFO experiment are presented. The test persons performs three types of tasks in this experiment: *Inspection of specific net holes*, *Overall inspection* and *Determining action using a framework*. First, the completion time of each of these three parts of the experiment will be presented, analyzed and discussed. In the end of the section, the total completion time will be analyzed and discussed.

The first part of the experiment, *Inspection of specific net holes*, the test person performed one-on-one inspection on some of the holes on the net. In the end of this part, comparisons between two holes were performed. From the results in Figure 5.1, one can observed that the test person complete this task faster using the AR system compared to the system without AR. The average completion time is 10.2 seconds faster with the AR

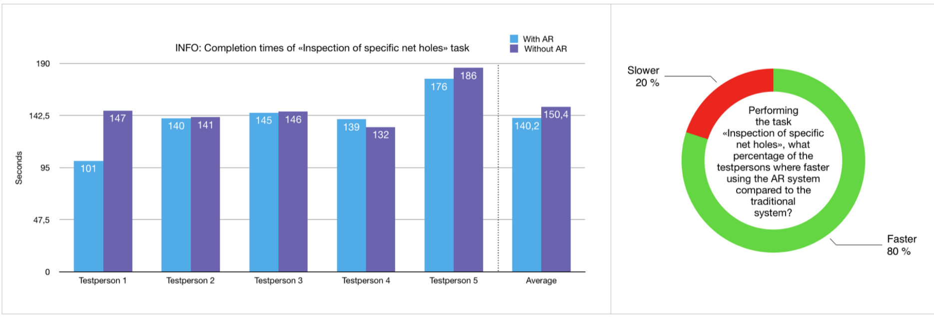


Figure 5.1: Results from the task *Inspection of specific net holes*.

system. 80 percent of the test persons performs this part of the experiment faster using the AR system. The differences in completion times between the AR system and the traditional system are not large for each test person. The exception is *test person 1*, where the AR system contribute to a large time saving of 46 seconds.

The results obtained are not surprising. With the AR system, the information needed to solve the tasks is presented directly with the video feed through the AR content displayed at the hole on the net. This created a two-stage process, where the test person first get the information needed directly through the video feed from the inspection, and then answer the questions related to the tasks. In the case where a traditional system is used, the process is in three parts: First the test person must do an inspection of the hole(find correct ID), match that ID with the associated information in the database, and then use the associated information to answer correctly on the questions in the set of tasks. It makes sense that an AR system will perform better in such one-to-one inspections, since the AR content is presented where it should be, namely at the net. With the traditional system the completion of the tasks is slower, since the test person uses extra time looking up the info from the database.

Since the five holes in this experiment are on an unrealistically small area, the time saving of 10.2 seconds become even larger if the holes are far apart like on a real fish net. Getting rid of an external database, and have all the information "connected" to the location of the holes, could both streamline the information flow and contribute to faster decision making. In real-world, the operation personnel could inspect a hole during net inspection, and save the info about the hole. When the hole is fixed in the second part of the operation, the AR information saved last time will be shown when the hole is detected again, contributing to added support when fixing the hole. The AR support could include outline and size of the hole for easier detection and visualization of the hole. From this part of the experiment, the AR have shown a prominent advantage displaying the information when and where it is needed. The test person can easily obtain the needed information to complete the tasks directly from the video feed from the inspection using the AR system. Hence, AR have shown promising results in operation where the information of one or a few specific holes should be obtained.

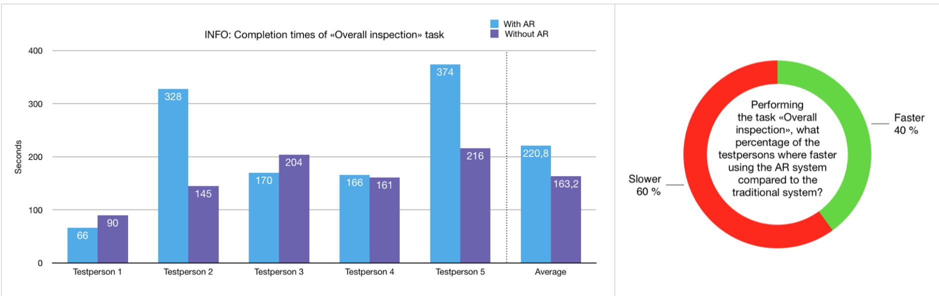


Figure 5.2: Results from the task *Overall inspection*.

In this part of the experiment, the test person had to analyze and gather information of all the holes at the net to solve the questions in the set of tasks. An overall evaluation of all the holes had to be obtained to solve questions related to the important attributes of all the holes. Performing this type of task, showed a decrease in the performance of the AR INFO system compared to the traditional system. In Figure 5.2, one can observed that the average time completing the tasks were 57.6 seconds slower for the AR system compared to the system without AR. Three out of the five(60 percent) test persons completed this task slower using AR than without AR. The difference is substantial for test person 2 and test person 5, where the completion time is 183 seconds and 158 seconds slower using the AR system, respectively.

When using the traditional system, the test person usually found the holes on the net with the associated ID, The IDs were written down on a paper, and from there, the test person used the database without doing any more inspections on the net. The associated information were gathered efficiently and fast when the IDs were found, and the tasks were completed fast using the associated information found in the database. When using the AR system, the test person had to frequently go back to the net to check things, since the information is only displayed at the net through AR, adding extra time completing the tasks. Another option is to take notes of everything of importance on the net during the first round of inspection using the AR system. To create this "self made database" would have added extra time, hence being costly related to the efficiency of the operation.

One of the test persons said that they missed the printed database from the part without AR, when dealing with this task using AR, since there was a overload of information to deal with. When dealing with a lot of information to solve the tasks, the system without AR using IDs and a printed database were superior to the AR system where all the information are displayed at the net. The location of the AR information is not contributing to solving the tasks fast, but is rather a barrier since the test person does not remember all the info, and therefore have to go back to check frequently. On the other hand, only looking into a database without inspection of the holes further is not wanted in a real-world operation. The support personnel can not look blindly on the information, since the net hole itself must be thoroughly analyzed to obtain a efficient real-world net inspection. An enhancement of *the system would be to use a combination of the two systems. When doing an inspection, an augmented database could be showing, and the test personnel could choose to either see detailed information about the specific hole inspected, or to see a database of information of all the holes on the net. This could give the test personnel a great overview of the situation of the net, but also detailed information about the local conditions of the specific hole inspected. Hence, an AR system must have the option to display larger blocks of data to deal with large comparison tasks like the Overall inspection task.*

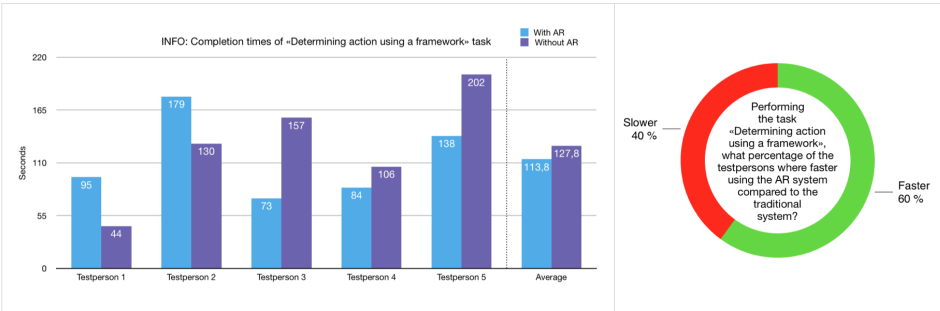


Figure 5.3: Results from the task *Determine action using a framework.*

In the last part of the experiment, the test persons were to determine how fast a hole had to be fixed based on conditions in a framework. The results presented in Figure 5.3 shows a slightly better performance using AR compared to using the system without AR. 60 percent of the test persons completed this task faster using the AR system, and average time completing the tasks were 14 seconds faster using AR. Compared to the two first parts of the experiment, the completion times are more variable in this part of the experiment. Test person 3 complete the task 84 seconds faster using the AR system, while test person 1 completes the tasks 51 seconds faster using the system without AR.

For some of the test persons, much of the information necessary to complete this task were already gathered in part two of the experiment through notes taken. The test persons taking notes in part two of the experiment using the AR system often performed better with the AR system in part three. This have nothing to do directly with the AR system, but the work process of the test person. In the case where the traditional system is used, no inspection is happening on the net anymore. All the focus is on the database, and finding the necessary information to complete the tasks. During real-world operations like that would be insufficient, since the support personnel must have full control of the drone to avoid collision with the net. If a database is used, two persons must do the operation, one two control the drone and one to simultaneously investigate the database. This adds cost to the operation. The test persons that performs better using the AR system already have taken notes and is ready to answer the questions head on. The test persons performing worse using the AR system have not gathered enough data already and have to go back to the net to check things adding extra time.

Therefore, the results and observations reveals a weakness of both the experiment and *the AR system. The performance of part three is highly dependent on the work done in part two, and since the parts of the experiment are intended to be independent and isolated, this is showing a weakness of the testing procedure. Second, the AR system is not contributing to better performance, but is rather a barrier to the information needed to complete the task, since if any of the information is missing a new inspection must be done instead of just looking up the information in a database. The AR system is slightly faster in this part of the experiment. Based on the variable results and the observations, this have not so much to do with the performance of the AR system, but more the format of the testing process. The test person have already tested this task using the traditional system, and with almost the same information the test person completed the tasks faster based on more experience.*

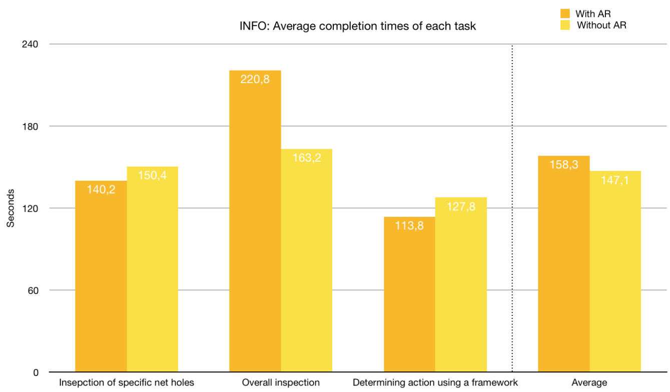


Figure 5.4: The average of the completion time of each task.

From Figure 5.4, one can observe that the tasks in part two of the experiment contribute the most to the total completion time. *In this part of the experiment many of the test persons had to take notes in addition to doing the inspection itself when using the AR system. Through observations and screen recording, one can see that the notes taken in part two of the experiment highly contribute to a faster completion time in part three of the experiment.* Both the tasks *Inspection of specific holes* and *Determining action using a framework* were performed faster using the AR system. *The overload of information in part two, and the fact the the information was not displayed in a suitable manner to solve the tasks using the AR system, resulted in a total average time that is higher for the AR system than the traditional system. These results indicates the importance of what kind of AR information, and where this information is displayed, plays a huge role on how efficient the AR could help and support personnel in real-world operation.*

Three out of five(60 percent) test persons performed better using the AR system instead of the traditional system. *With only five test persons, these results are not impressive, but they indicate that AR is a promising technology which could give an advantage and edge in aquaculture operations with the necessary enhancements.* The total completion times

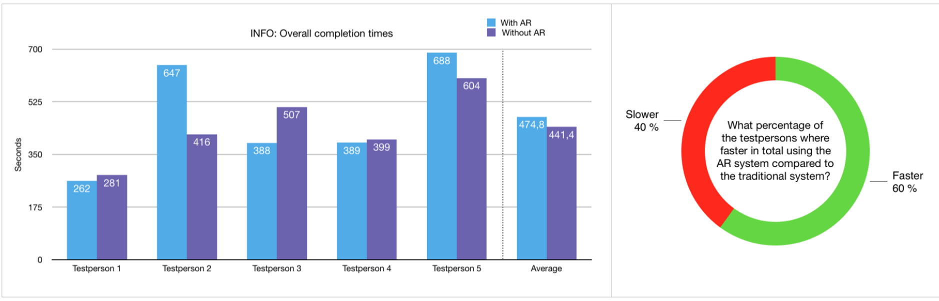


Figure 5.5: The completion times of each test person completing the tasks in the INFO experiment(left). The percentage of test persons completing the tasks faster using the AR system(right).

were 33.4 seconds slower when using the AR system. *This is not an substantial difference from the performance of the traditional system, but it is neither an enhancement. The AR system is a great tool for providing information in a clear and informative way, but one must consider what information is displayed, when it is displayed and how it is displayed. These are more broader problems, which will be looked at more closely in the Discussion chapter.*

As said before, part two of the experiment is highly contributing to the large total completion time for the AR system. On the other tasks the AR system is performing as well as the traditional system(or even better). From the results in Figure 5.5, the completion time and the difference between AR and no AR is highly variable between the test persons. Many factors play a role on how fast each task is performed: How confident the person is interacting with the system, how stressed they are by the testing procedure and how motivated they are conducting the experiment. Some of the test persons may have a harder time learning the AR system, and therefore uses extra time to get to know the systems. While other test persons were more overwhelmed by all the information in the database. These differences play a critical part when conducting such an experiment over a rather short time frame. The AR INFO system have shown strong performance in one-to-one inspection of the holes, but enhancement must be made to handle larger blocks of data during inspection.

5.1.2 Subjective evaluation

After the experiment, each test person completed a subjective evaluation to evaluate and compare performance and usability of the AR system and traditional system. The first part of this section will present results from the part of the subjective evaluation where the performance and usability of the AR system and the traditional system were compared. The second part will present results from the part of the evaluation where a more thorough evaluation of the AR system is conducted. All results presented are discussed and analyzed consecutively.

AR INFO system vs traditional system

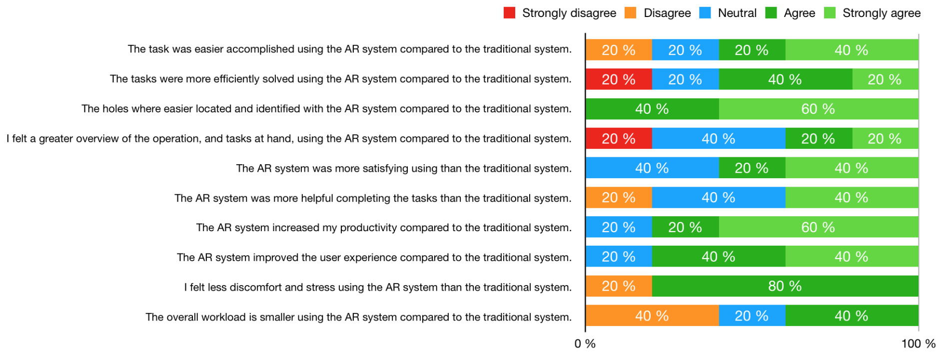


Figure 5.6: Statements to evaluate performance of AR system compared to the traditional system, based on defined usability goals.

From the results in Figure 5.6, one can observe that the satisfaction of the AR system is high compared to the traditional system. The AR system scores high in the factors *Satisfaction*, *Effectiveness* and *Situation awareness*. In many of the categories, one or two test persons answer *Neutral*, indicating no difference between the AR system and traditional system. All the categories, except one, have one or two test persons meaning there was no difference in using the AR system over the traditional system in that specific category. This indicates that the experience of using the AR system is highly variable. Some of the test persons think the AR system made a huge difference in some categories, while other saw no difference, or a AR system operating in a worse way than the traditional system.

In some of the statements some of the test persons are not satisfied with the way the AR system operate compared to the traditional system. In the statement *The task was easier accomplished using the AR system compared to the traditional system*, one of the test persons disagrees. *This could be related to the part of the experiment where the Overall inspection task was completed. The overload in information experienced here, where the test person had to take notes in addition to doing inspection on the net caused an overload in information compared to using the IDs and database of the traditional system. Another cause could be that the test persons was efficient in using both the AR system and traditional system.* One of the test persons *strongly disagree* with the statement *The tasks were more efficiently solved using the AR system compared to the traditional system. The test persons could strongly disagree on the same basis as the test person that disagrees on the first statement. The AR system did not perform sufficiently when doing inspection on many holes at the same time, gathering a lot of information about the holes.*

The statement *I felt a greater overview of the operation, and the tasks at hand, using the AR system compared to the traditional system* had one person strongly disagrees with the statement. On the same statement, two of the test persons are neutral to the statement. *This indicates that the situation awareness using the AR system is not the best while per-*

forming the tasks. During drone operations, knowing what goes on around you is very important, and to sufficiently operate the drone, full overview of the operations is crucial. That three of the test persons sees worse or no enhancement with the AR system indicates that the AR system must be changed to create better overview of the situation. Three of the test persons either disagree or is neutral to the statement *The AR system is more helpful completing the tasks than the traditional system*. *If an AR system should be used, it must be more helpful than not using any AR system. This results indicated that the AR system is not suitable in some of the parts of the experiment. An interesting evaluation could be to have the same evaluation on each of the task completed. The AR system could be more helpful in the one-to-one inspection, while in the overall inspection the overload of information is not handled correctly by the AR system created.*

The two last categories are related to the workload of the operations. One test person felt more discomfort and stress using the AR system while completing the tasks. When dealing with underwater operations, the goal of AR is to reduce stress and discomfort. Added stress and discomfort during drone operation could cause mistakes and errors that could lead to fish escaping, collisions or other thing that is not wanted. The rest of the test persons felt a reduction of stress and discomfort when using the AR system. *Nevertheless, people can make mistakes under operation, and no one should feel added stress and discomfort from the AR information during operation.* Two test persons experienced a higher workload using the AR system. *This is not surprising, observing the results from the completion time section. The added overload of information in part two and three of the experiment increased the workload and mental capacity needed to solve the tasks. With the traditional system, the information were easier to obtain faster, and therefore the workload was higher using the AR system, since net inspections had to be done to check information over again instead of just looking it up in the database. The goal of AR is to decrease workload by applying supporting information at the right time, at the right place. The results indicates that enhancement can be made in concern of the factor Workload.*

A solution, or enhancement, was proposed by one of the test persons related to handling larger blocks of data:

"I think I would get a better overview of the information if the numbers I got using the AR eg. was automatically added to a database. If I didn't remember one thing, moving the stick with the camera was more work than just checking a database where all the information was gathered."

The solution proposed is a combination of using the AR system, and then have a database where data is automatically added when detected. Such system could work very well, but must include some sort of cloud system to safely save the data.

The results in Figure 5.7 indicate that the test persons overall were satisfied with the AR system when related to *faster learning*, *better access to information* and *faster gathering of relevant information*. These are characteristics of an AR system that may be beneficial in underwater operations. One of the test persons did not see any progression in *faster learning* when using the AR system. Overall, the results were positive in favor to the AR system.

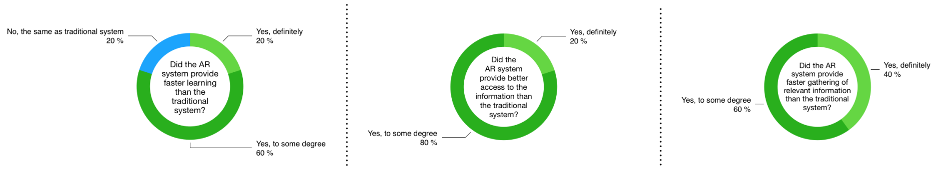


Figure 5.7: Results from questions comparing the AR INFO system and the traditional system.

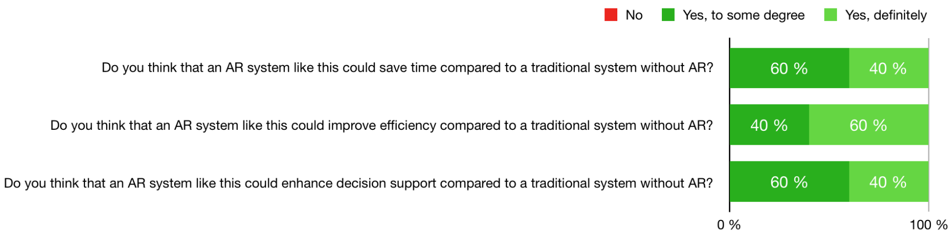


Figure 5.8: Results from questions comparing the AR INFO system and the traditional system.

The test persons were very positive of AR and the future of this technology related to underwater drone operations, as seen in Figure 5.8. All the test persons meant that the AR system could save time, improve efficiency and enhance decision support in a moderate to high degree. *The questions could be biased, since the last alternative being* ***No****, which is a very drastic answer on such question.* But the test persons seemed satisfied and optimistic on behalf of the AR technology after testing it in this experiment.

Detailed evaluation of the AR INFO system

Looking at the answers of the statements in Figure 5.9, we observe that the overall opinion is that the AR systems works in a suitable manner. One test person disagreed on *feeling confident in properly solving the tasks* using the AR system. The statement related to situation awareness, *I had a great overview of the operation and the tasks at hand*, one test person disagrees. *There could be many reasons for disagreement on these statements, related to the test procedure, misunderstandings of the tasks at hand or the AR system itself.* One of the test persons also strongly agrees that the AR system provided them with too much information. *This is the only question that is formed in a negative way in the regard of the AR system. One possibility is that the test person was not satisfied with the AR system, and meant that the system provided them with to much information or too many unnecessary AR components. Another possibility is that the test person were tired of answering evaluation questions or misunderstood the question. That almost all the question is formed in a positive way related to the AR system, may cause a bias, since the predefined threshold for answering negatively towards the AR system is higher.*

The ID board is the first AR component seen by the test person, since it is visible far away from target/hole. The response of the user interface, design and usability of the ID

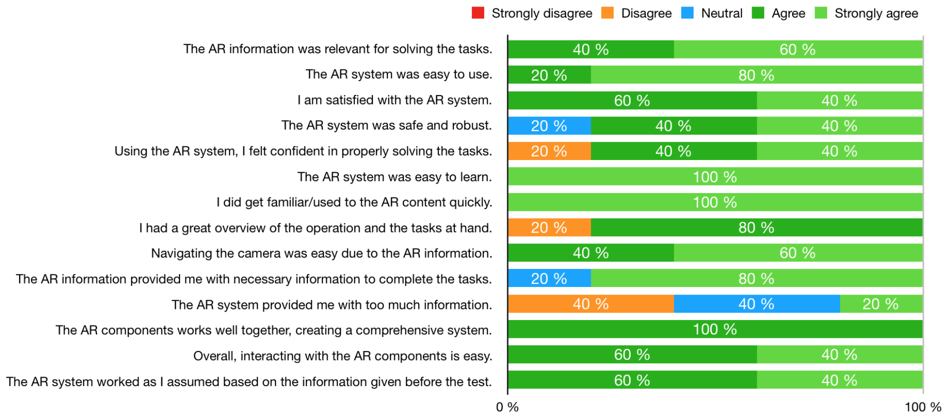


Figure 5.9: Statements to evaluate performance and usability of the AR system based on defined usability goals.

board is overall positive or very positive, seen in Figure 5.10. The test persons thinks the AR components is helpful, easy to interact, necessary and intuitive. In some of the categories, one or two test persons have answered neutral on the opinion of the statement. This indicate that the ID board did not gain any clear advantage in that specific category in design or usability. One of the test persons means the font size of the ID text was unsuitable. *The ID text could have been made in an even larger font to get more attention from the user, or made smaller so that the ID board is not covering the hole. Both alternatives would have made an improvement in one way or another. From the evaluation one of the test persons meant that the ID text could be hard to read, and that it should be moved to the middle of the ID board to ensure that all the black text have green background. This is a possible improvement that would have ensured better readability.*

One of the test persons meant that the scale of the ID board is unsuitable. *The reason for this could be that the ID board is covering the whole location of the hole. This was a choice made in the design process. At larger distances, detailed inspection of the hole is hard to achieve, and the focus should be to localize the position of the hole. This is done in a better way using larger AR components to highlight position. Nevertheless, the test person might have a point that the ID board covering the hole completely could cause bad visibility and visualization when doing operation underwater. An ID board could have been used, but maybe not covering or hiding the hole. This could make a better overview of the operation. The ID board disappears when the test person is approaching the hole with a certain distance. Some of the test persons were confused by this, and asked why to the ID board disappear? and Where is the hole with ID:11?. These questions indicate that it was a little confusing, when the ID board disappears. Then to find the ID again, the test person must go further away from the hole to see the ID which are both physical demanding and takes extra time during operation. A possible improvement would be to show a line where the ID is written in a smaller text or to show the ID board in miniature to have some consistency in the design of the AR system.*

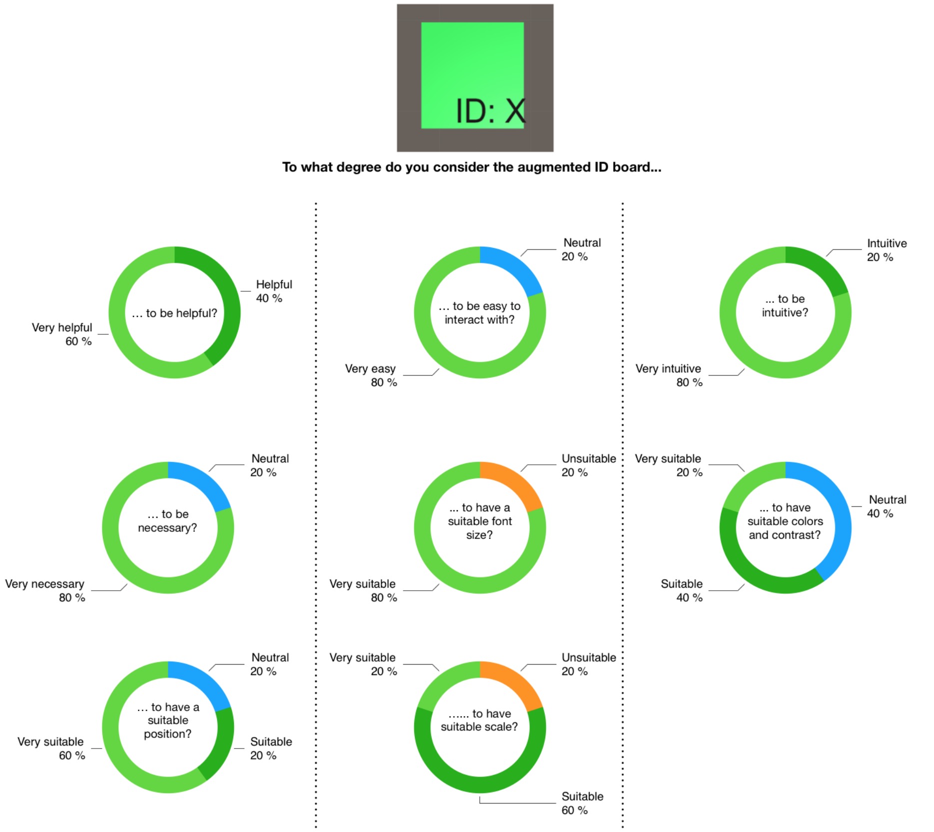


Figure 5.10: The evaluation of the AR component *ID Board*.

At a certain distance, when approaching the hole, the arrows with IDs to nearby hole is displayed to improve navigation and overview of the operation. This is one of the AR components that the test persons are the most satisfied with, as seen in Figure 5.11. All categories, except one, have answers that are only positive or very positive. One test persons answers *neutral* on the question *Is this AR component necessary?*. *Most probably, the test person have been able to locate the holes without the AR arrows, but they make the navigation on the net much faster since the test person do not have to search all over the net to find the hole with the correct ID. The AR arrows are helpful and intuitive in that way that they point the test person in the correct direction making the inspection path more accurate and fast.* The design of the arrows did also get a great response. The scale, position, font size and colors and contrast were correctly chosen based on the positive response of the test persons. *This indicate that the AR components did not get in the way of the operation, but helped with navigation and that the readability and the length and colors of the arrow, dependent on distance to nearby holes, were intuitive. The last statement only*

Figure 5.11: The evaluation of the AR components *Direction arrows with IDs*.

amplifies the fact that the arrows made a huge impact on the navigation. 80 percent, four out of five test persons, meant that the arrows with ID made a *very large enhancement* of the navigation.

Despite all the positive response, some changes could be made to enhance the AR component even more. The ID text must be changed to another color than blue for underwater operations. The blue color of the ID text works well over water, but may have bad readability when under water since the contrast will be small relative to the environments(which in most cases are blue). This is an easy fix, changing the color to something with a high contrast to water, using a warmer color like red, yellow or orange. The distance to nearby holes, with units, could have been added. The ID text could have been ID:9(12 m), which could have made a more clear picture on how far away the different holes are. One test person pointed out that the arrows should not only include nearby holes but all the holes on the net. This is a good point when the system is up scaled to be used on an actual fish cage net. In smaller scale highlighting only nearby hole would work. Since there often are no nearby holes on the fish cage net, pointing to all the holes detected would be suitable to ensure that all holes are inspected and repaired.

The outline of the hole with size is made to easier visualize the hole and to easy gather

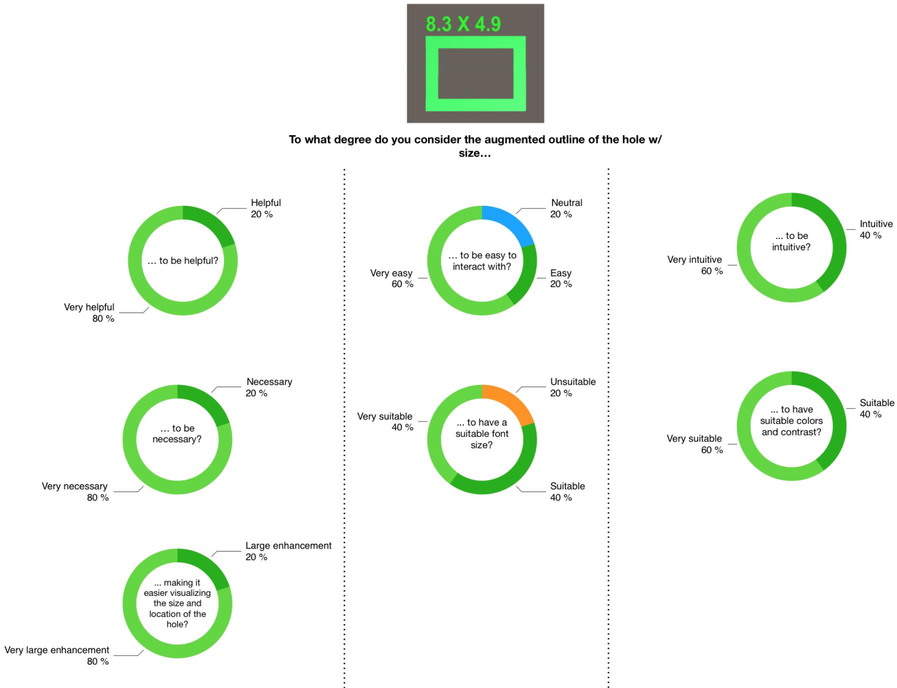


Figure 5.12: The evaluation of the AR component *Outline of hole with size text*.

the information of the size of the hole inspected. The overall response of the AR component is positive, as seen in Figure 5.12. Most of the answers in the different categories is either positive or very positive. The outline is an important part of the AR system, supplying the test persons with the size of the hole, and easy visualization of the size and position of the hole. One test person means that the AR component have an unsuitable font size. *The test person may think the font size is to small, so that it is hard to get the size of the hole. Another point is that the text is moving dynamically relative to the outline. This may cause the size text to be hidden behind the outline, making it hard to read from some angles. This could be fixed by setting the size text static relative to the outline of the hole, ensuring great readability from any angle. Another possible enhancement is to add units to the text indicating size. This is an important improvement, since the personnel must know the exact size when inspecting the hole.*

The status board is showing important information about the attributes of the the hole used to answer the questions in the set of tasks. The test persons are overall positive or very positive in almost all categories of the evaluation of the AR component, seen in Figure 5.13. *The status board is a crucial components for solving the tasks present in the experiment, so it is no surprise that the component scores high in categories like helpfulness, interaction, necessity and intuitiveness.* The position and scale of the status board does also get only positive or very positive response. One of the test person thinks that

Figure 5.13: The evaluation of the AR component *Status board*.

the status board have an unsuitable font size. *The text may be hard to read, if the text is too small.* Four out of five test person answers neutral on the statement related to the text having suitable color and contrast. *The readability of the text may not be the best, since some test persons are not fully satisfied in these categories.*

In the evaluation, one of the test persons would have had more padding on the status board to ensure that none of the text is not in front of the yellow background. When the text is outside of the edges of the status board at some angles, the text is harder to read. Another test person pointed out that there were too many different colors on the test board, and if the colors of the text were of the same color, it would have been easier to read and gather the information. To enhance the presentation of the status board, some suggestions were presented by the test persons. The text in parenthesis indicating how long since the hole is detected could be on a row alone, like Days since detected: 26. This could better the overview, and making the information more easy to read. To lower the workload, one suggestion was to add a row to indicate when the hole had to be repaired, like Need to be fixed: Within a day. In the experiment, a framework is used to determine when to repair the hole, but in the real world it would be more realistic to add such row indicating when *the hole have to be fixed. The calculation of when to fix the hole would have been carried out easy and instantly by the computer using conditions like the ones in the framework used in the experiment.*

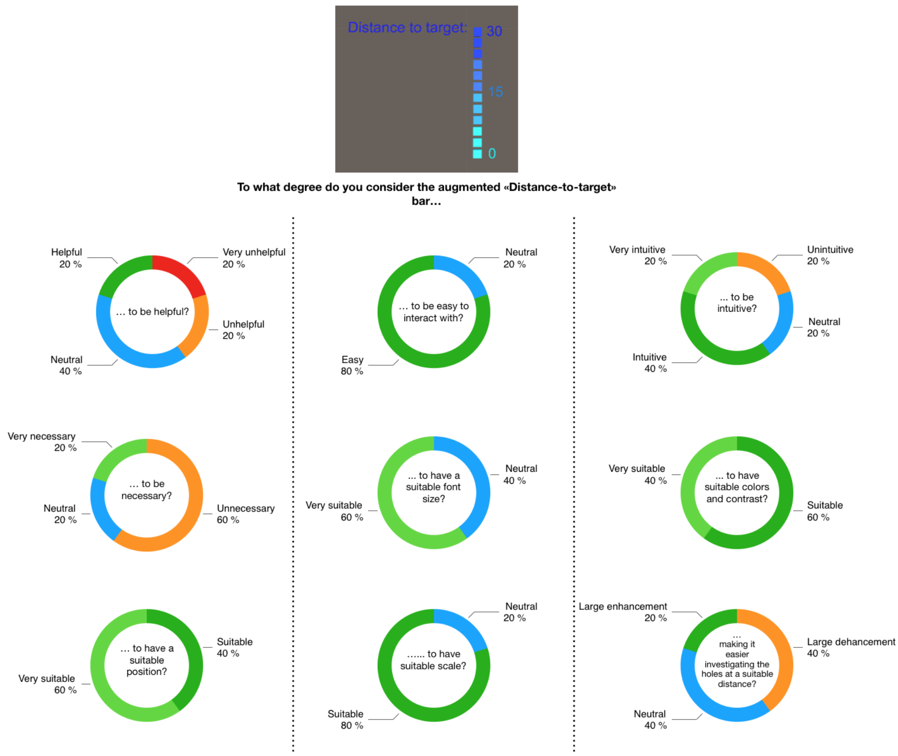


Figure 5.14: The evaluation of the AR component *"Distance-to-target" bar*.

The distance bar is meant as a mean to accurately visualize the distance to target, to do inspection at suitable distance and to avoid collisions with the net. The AR component is meant as a supporting aid, and is not directly necessary to solve the tasks at hand. This is shown in the evaluation, where three out of five test person means that the AR component was unnecessary to complete the tasks, as shown in Figure 5.14. Only one persons though the bar was helpful completing the experiment, the rest answered *neutral*, *unhelpful* or *very unhelpful* on this statement. One test person also thought the distance bar was not intuitive. *This is understandable, since the AR components is not contributing in solving the tasks to complete the experiment. Since the component is not contributing to the results directly, it is maybe more in the way of the operation, than helping completing it.* The categories related to the design of the AR component, the response is either *neutral*, *suitable* or *very suitable*. *In other words, the design of the AR components is accepted by the test persons. The color of the bar must be change for underwater operation, since the blue distance bar* *will not have enough contrast to the environment underwater to be easily seen. One of the test persons did not observe the distance bar during testing, saying that "... I would have used it more actively if I had observed it". This indicates that the bar should have been in colors with more contrast to the environment.*

In the last statement asking *Is this AR component making it easier investigating the hole at a suitable distance?*, two out of the five test persons think that the distance bar is a large dehancement related to the statement. *This indicates that the distance bar is not achieving the function that was purposed for this component. One enhancement of the bar would be to add measurement units to the scale. The scale is in centimeters but this should have been better communicated through measurement units on the numbers of the bar.*

Figure 5.15: The evaluation of the AR component *Local map*.

The local map was added to the AR INFO system to enhance navigation and give a better overview of the situation at the net. The response of the local map is mixed, as seen in Figure 5.15. Some of the test persons said that they did not use it, or had to use it, to solve the tasks in the experiment. *It was pointed out that the local map would be more necessary in a bigger scale operation, since the test scene used in the experiment was too small to see the function of the local map.* In many of the evaluation categories and statements, a large portion of the test persons answers *neutral*, since the local map was not used by many of the test persons while testing the system. In both categories about *helpfulness* and *necessity*, one test person means the the system is not helping or is necessary. *Since most of the test persons did not use the Local map actively in the testing, this is an expected result.*

In the last statement which ask *Did the AR component provide easier navigation?*, the answers were highly variable, ranging from *Very large enhancement* to *Large dehancement*. *One test persons pointed out that the arrows contributed more to easier navigation than the local map. The key difference was that the arrows had IDs on them, to show where specific holes are. One possible enhancement of the local map is to add such IDs on the holes shown in the map. This would increase the information about the holes, and making it easier navigating to the hole with one specific ID. The local map should also be incorporated in such way that it is easier to see during operation. Some test persons did not use it, and some did not even see the map while testing. The position of the map should be changed for easier use. The title could also have been written in a larger, bolder text to be shown better.*

Figure 5.16: The evaluation of the AR component *Alert*.

The AR component *Alert* was added to the system to avoid collisions with the net/test scene. The alert pops up in front of the hole when the camera is less than 10 centimeters away from the AR marker framing the net hole. From observations and screen recording, it can be observed than only two out of five test persons came close enough to the hole to interact with the alert. The results show sign of less interaction, since most of the answers are *neutral*. The test persons interacting with the alert seems satisfied with both the interaction, design and usability of the alert. In each of the categories concerning *Helpfulness*, *Intuitiveness* and *Necessity*, one test person is not satisfied with the alert. *This makes sense if the test person never interacted with the alert, or felt that the alert did not supply any support achieving the tasks. Hence, the alert was a part of the AR system that did not help achieving the tasks at hand.*

5.1.3 Workload: NASA-TLX

In this section, the results from the evaluations of the workload done in the NASA-TLX app, are presented. All the results presented are analyzed and discussed consecutively. In the first part of the section, the average of the adjusted ratings(the combination of the weights and rating) of each workload factor are presented. Then in the end the weighted ratings of each test persons is presented. The procedure of the evaluation is described in detail in the *Theory and background* chapter.

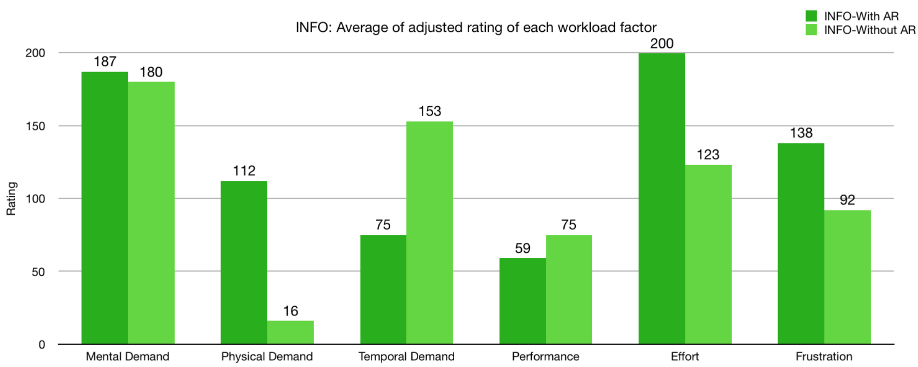


Figure 5.17: The combination of the weights and ratings creating the overall evaluation of each workload factor.

The adjusted rating of each factor is calculated by multiplying the weights of each workload factor with the rating of each factor. From the results in Figure 5.17, one can observe that the workload factor *Mental Demand* is contributing heavily using both the AR system and the traditional system. This means that the test person experience a high mental demand when doing the tasks. *The goal of the AR system is to lower the overall mental demand by supplying the correct information at the right location, so that the AR system are scoring 7 points higher than the traditional system in this category, indicates the AR system have failed accomplishing this goal of the system. That the mental demand* *is high in this category is not surprising, since during the experiment the test person must calculate and remember information to complete the tasks. Using the AR system in the tasks Overall inspection and Determining action using a framework, much information must be remembered to complete the tasks, and if something is forgotten or not written down, the test person must get the information again by doing an inspection on the hole. Using the traditional system, all that has to be remembered is the ID of the holes, the rest is written in the database and do not have to be remembered. That the test person must remember more information using the AR system is creating the difference in favor to the traditional system in this category.*

The workload in the factor *Physical Demand* is substantially lower using the traditional system than the AR system(16 versus 112). *That the physical demand is smaller using the traditional system is not surprising. Through observations, one can see that the test person is not doing much more inspection on the net after collecting the different IDs of the hole on the net. Further, the focus is then on the database and completing the exercises. With the AR system, the inspection must be done throughout the entire experiment, unless a lot of notes are taken. This means the experiment is more physical using the AR system, since the stick must be moved more to obtain enough inspection. The physical workload is not directly comparable to a drone operation, since the workload of steering a drone compared to moving the stick in the experiment is lower. But it is worth a mention, since it means that using the AR in a wrong way may cause more physical demand in operations.*

The *Temporal Demand* is higher for the traditional system(153) compared to the AR system(75). The test person experienced less time pressure using the AR system. *The reason could be that the AR system supplied the test persons making the tasks easier to complete and made the test person more confident in completing the tasks. Another reason could be that the test person already have tried the test procedure one time with the traditional system, and was more experienced so that the time pressure were lowered through this experience.* The factor with the lowest overall score is the *Performance* factor. The test persons felt confident in completing the tasks in a good manner, and felt satisfied with their own performance completing the tasks. The confident and satisfaction of the test person is a little bit higher, with a score of 59, using the AR system than the traditional system, that have a higher workload with the score 75. *Again, this can be through the performance of the AR system or that the test person is more experienced with the testing procedure in the second run of the testing.*

The workload of the AR system is much higher than the traditional system in the workload category *Effort*, with the rating of 200 and 123 respectively. This indicate that the test person had to work much harder, both physically and mentally, to accomplish the performance of the test person using the AR system compared to the traditional system. *This makes sense in the context of the workload factors Mental Demand and Physical Demand where the AR system scores the highest in both. The large difference in this category is caused by the mental overload using the AR system in the two last parts of the INFO experiment, and that the test person must do more inspection completing the tasks using the AR system, hence higher physical workload.* The last category is *Frustration*, where the

AR system is scoring higher than the traditional system, with the rating of 138 and 92 respectively. *This is another example of the AR system failing in one of the goals that AR want to accomplish. AR must lower the degree of frustration during operations to achieve added help and decision support. Since the categories mental demand, physical demand and effort is higher for the AR system than the traditional system, it is quite natural that the test person would feel more frustration during the testing. This result could be caused by both the testing procedure, and the AR system itself. The testing procedure could be made in such way that the AR system is not used in a suitable manner. Or the AR components creating the system are not helping enough to accomplish the tasks, hence not giving enough support to lower the frustration of the test person.*

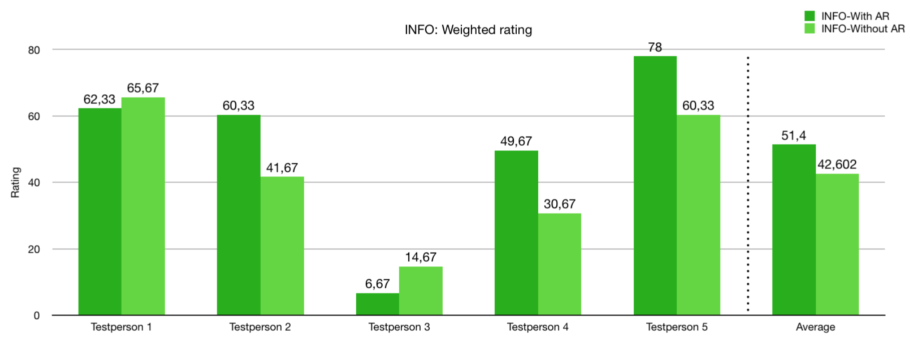


Figure 5.18: The weighted rating of each test person and the average of the weighted ratings.

The weighted ratings are the overall measure of the workload of a specific task, combining the score of all the six individual workload factors. In Figure 5.18, one can observe that the average of the adjusted ratings are higher for the AR system compared to the traditional system, with ratings of 51.4 and 42.602 respectively. *Analyzing the contribution of each workload factor in the Figure 5.17, this is not surprising. Especially the factors Physical Demand and Effort are contributing to a higher total workload for the AR system. The higher workload for the AR system is caused by a number of reasons. Firstly, the mental overload of the information in the parts Overall inspection and Determining action using a framework discussed earlier. Secondly, the physical demand is much higher using the AR system, since much more inspection is needed to keep track of all the info in the experiment. These are the main reason the workload is higher for the AR system.*

The weighted ratings is highly variable between the test persons. Test person 3 is experiencing a very low overall workload, test person 2 and 4 are experiencing a medium to high workload, while test person 1 and 5 are experiencing a high workload using both the AR system and traditional system. *These variances are natural, and through observations different ways to perform the tasks are seen. Some methods are more efficient than other. Some persons are better at operating the stick, gather information and taking notes while testing. These factors play a great part in the measure of the overall workload.*

5.2 Results of the INTERACTION experiment

The next sections will present the results from the INTERACTION experiment. Completion times of tasks, data from the subjective evaluation and measures of workload through the NASA-TLX app are presented and discussed consecutively. Objective observations of relevance are also discussed and analyzed.

5.2.1 Completion times of tasks

In this section the completion times of the INTERACTION experiment are presented, analyzed and discussed. The overall time included the time from the stick have been detached from the docking to the marker with net is attached to the AR frame marker fixing the last hole in the test scene.

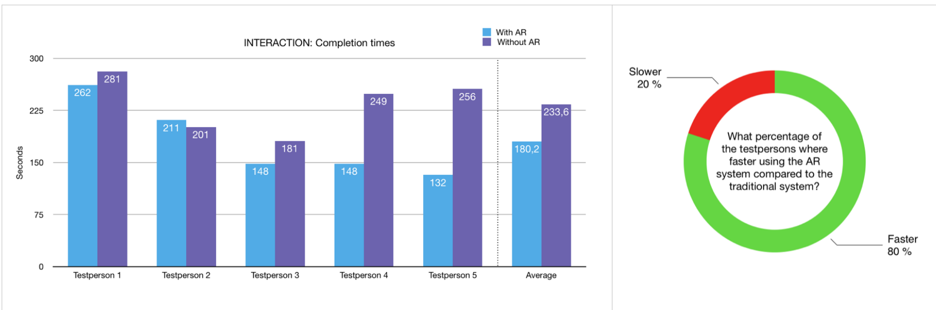


Figure 5.19: The completion times of each test person completing the tasks in the INTERACTION experiment(left). The percentage of test persons completing the tasks faster using the AR system(right).

Using the AR system, the test person is 53.4 seconds faster fixing the four holes compared to the traditional system. This is a substantial difference since the entire operation takes on average 180.2 seconds and 233.6 second for the AR system and traditional system respectively. Four out five test persons(80 percent) performed better and achieved the tasks faster using the AR system. *From observations, the test persons seemed faster and more accurate approaching the attachments in the test scene using the AR system. On the other hand, the traditional system were tested first, and a lot of experience on how to interact with the hardware could have been gained in the firs walk-through of the test procedure.* Nevertheless, the performance of the AR system is very consistent, except with test person 2, where the AR system performed worse than the traditional system.

The combination of enhanced positioning support of the stick and the augmented information, makes the AR system more efficient completing the tasks. With the traditional system, finding the holes ID and then look-up the necessary information, before finding the correct marker using the printed framework, adds extra time to the operation. With the AR system all the necessary information is gathered directly at the net where the hole is *located. The size of the hole and the associated color are showing what marker to get to fix the hole temporary. When attaching the stick to the marker with net, and when the marker with net is attached to the AR marker to fix the hole, the added positioning support through the depth indicators and direction arrows help the test person performing the operations in an efficient, calm and fast manner. These factors, with the potential added experience from the first test run with the traditional system, makes the test persons completing the tasks faster using the AR system.*

5.2.2 Subjective evaluation

Each test person completed a subjective evaluation after the experiment, to evaluate the performance and usability of the AR system compared to the traditional system. The first part of this section will present results from the evaluation comparing the AR system and the traditional system. The second part will present the results from the more detailed evaluation of the AR INTERACTION system. All results presented are discussed and analyzed consecutively.

AR INTERACTION system vs traditional system

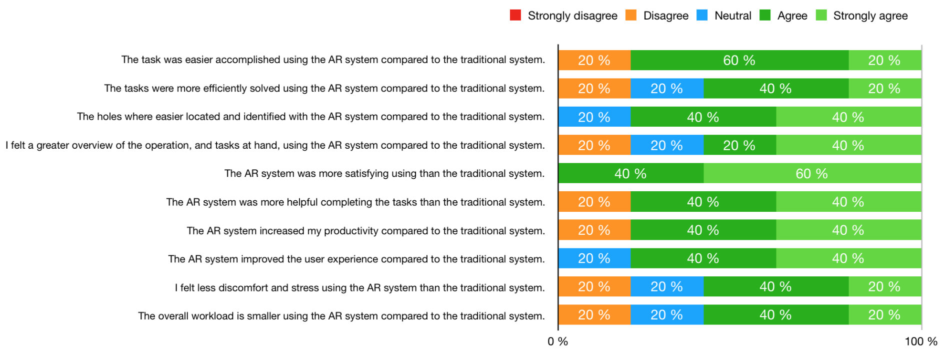


Figure 5.20: Statements to evaluate performance of the AR system compared to the traditional system, based on defined usability goals.

From Figure 5.20, one can observe that the overall performance and usability is evaluated to be better than the traditional system. In most of the categories the answers are positive or very positive. Some of the categories, the test persons have answered *neutral*, indicating that the AR system did not do any difference in the performance and usability compared to the traditional system. The objective observations during testing and the completion times emphasizes this result, since the test persons performed both faster and more confident using the AR system.

In many of the statements, one of the test persons have answered *Disagree*, indicating that they are not satisfied with the performance or usability in the specific category. The two first statements measures the ISO factor *Effectiveness*, and one test person did not believe the task were easier and more efficiently solved with the AR system. One test person is also not satisfied in the categories related to helpfulness and productivity, related to the ISO factor *Effectiveness*. *The reason could be that the AR system did not supply the test persons with necessary information, or that the AR system was not designed in such manner that it helped during operation. Some of the test person had some question related to the AR content of the positioning support during the experiment. To avoid the occlusion, the support panel may have a non-intuitive position causing more confusion than help. This will be more thoroughly discussed when the results from the detailed evaluation of the AR INTERACTION system are discussed.*

One of the test persons is not satisfied with statements concerning *Situation awareness*, where the test person is asked if the AR system is providing a better overview of the situation and tasks at hand. *This result is not surprising, since the AR system does not have any components to create overview of the operation, in such way the AR INFO system have(direction arrows and local map). But the info at the holes and the positioning support should give better overview in the operation itself. Perhaps the test person were not satisfied with the design of the AR components, being more in the way than helping. Another reason could be that the test person thought the test procedure using the traditional system were more easy, using the printed information and framework to find correct marker of the hole. This is most probably the case, since this is the one person completing the testing procedure faster with the traditional system than the AR system.*

The two last statements concerns the factor *Workload*, and here one test person means that the workload is not lowered using the AR system. The test person felt more stress and discomfort, and felt the overall workload were higher using the AR system. *One of the main goals of AR in general is to lower the workload. For this test person the AR system failed in one of the most crucial goals of the AR system. The AR system did not lower the workload related to detection and inspection of the hole, and through the added decision support to operate the stick. That the test person is experiencing a heavier workload could be related to the testing procedure and that the AR system is not contributing in such way that the test person gets the support needed to achieve the tasks more efficiently. The support panel related to positioning may be experienced to be more confusing than helping, making the process of positioning the stick correctly attaching it to the attachment more stressful and uncomfortable. From screen recording one can observe that the support panel is unstable in the sense that it suddenly is not showing when the stick is attached to the marker with net. This did not happen regularly, but may be a contribution to a higher workload. The robustness of the system is further discussed in the section of the detailed evaluation of the AR INTERACTION system.*

The results of the questions comparing the AR system and traditional system in Figure 5.21, shows that the AR system for the most parts is achieving *faster learning*, *better access to information* and *faster gathering of relevant information*. *The AR system is displaying info about the hole size and outline of the holes directly at the hole compared to using an external database and framework of some sort, hence providing better access to*

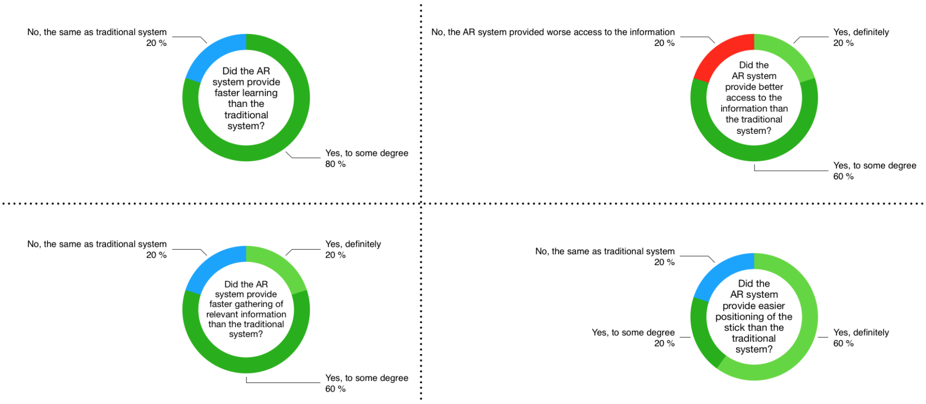


Figure 5.21: Results from the questions asked to compare the AR system with the traditional system.

the information. The position support helps the test person learning how to guide the stick to the attachments in a more accurate and fast manner. The faster gathering of information is a natural cause, when the AR information is displayed directly at the hole or the attachments in the test scene. The test person get all information needed to solve the tasks from the AR in the test scene, and does not have to use external documents with information to solve the tasks.

Answering the questions, some of the test persons did not see any enhancement using the AR system related to faster learning, better access to the information and faster gathering of relevant information. *These test persons may have been fast achieving the tasks with both the AR system and traditional system, and experiencing no difference in the efficiency using an external framework compared to using an AR system. One test person means the AR system is providing worse access to the relevant information in the test scene. The test person may be more satisfied with having all the necessary information on an external document, instead of searching the scene. When using the traditional system, all the test person had to do was to find the ID in the test scene, and then use the information on the external paper with info and framework to find the correct marker with net. This test person may have thought this process provided easier access to the information, than searching the net operating the AR system to find the info. To find the correct info about the hole, the test person must approach the AR marker at the hole to "unlock" the necessary info to find the correct marker with net, and the test person may have found it more easy to access the info through the framework and IDs at the holes.*

The last question ask *Did the AR system provide easier positioning of the stick than the traditional system?*. This is one of the most important aspects to test in this experiment. The response of the test persons is overall positive or very positive. One test persons is neutral to if the AR system is providing easier positioning. *This indicate that the goal of achieving better positioning with the AR system is achieved. The results show that the positioning panel with depth indicators and correction arrows is helping the test person,* *and achieves an edge when the test person is navigating the stick during testing.*

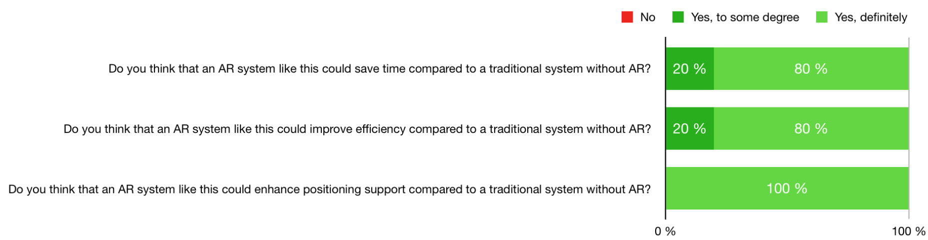


Figure 5.22: Results from the questions asked to compare the AR system with the traditional system.

In Figure 5.22, the test persons responses are overall positive on the potential of using such an AR system in real world operations in aquaculture. After testing the system, they think the AR system could save time in operation in a moderate to high degree. The test persons also think an AR system like this could improve efficiency during operations. *Since all but one performed the tasks faster using the AR system, these results are not surprising. The additional AR information may improve efficiency through more streamlined information flow and added instruction supporting in positioning and interacting with different objects at the aquaculture site. The last question answered by the test persons emphasizes this, where all the test person are highly positive that an AR system such as the one in the experiment could enhance positioning support compared to a system without AR. This concludes that the AR system is promising for use in real-world underwater operation. Ideas of AR components and functions of the AR system used in this experiment, may give ideas and form a basis or a start for designing a real system operating in UID operations in aquaculture.*

Detailed evaluation of the AR INTERACTION system

The statements evaluating the performance and usability of the AR system given in Figure 5.23, show an overall positive response of the AR system. The first three statements shows that the AR system achieves a high degree of *efficiency* and *satisfaction*. In the statement asking if the AR system were safe and robust, one persons answers neutral on this statement. *Through video recording one can observe that the positioning panel with the depth indicators and correction arrows is not showing since the AR marker is not detected. This could be the reason this test person is neutral to the safety and robustness of the system.* The statements related to the factor *Learnability* have a high score with only positive or very positive responses. *Since this AR system in not the most complex related to function and information flow, this result is not surprising.* The rest of the statements concerning the ISO factors *Efficiency* and *Satisfaction* have responses that are either positive or very positive. Hence, the AR system scores high when measuring the satisfaction and performance given during testing of the AR system.

In two categories, one test person disagrees on the AR system creating an enhancement

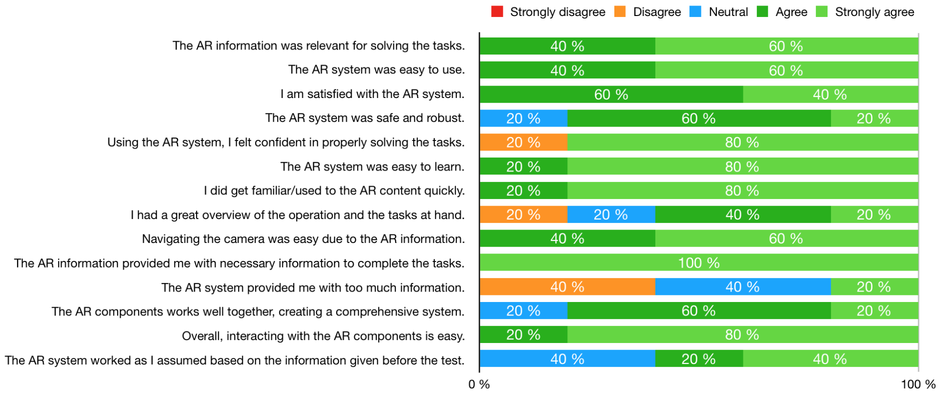


Figure 5.23: Statements to evaluate performance and usability of the AR system based on defined usability goals.

during the operation. The first statement is the one asking *if the test person felt confident in properly solving the tasks using the AR system. The test person may have been less confident caused by the positioning panel showing inaccurate information or not being displayed at all caused by the system being unstable when attaching the stick to the markers with net. Observing the test persons during testing, this is the most probable factor to the dissatisfaction.* The other statement is related to *Situation awareness*, where the test person did not feel a great overview of the operation and tasks at hand. *There could be many reasons for this, but the AR system may not give enough support when attaching the stick to the attachments. The AR information may be inaccurate, giving inaccurate correction instructions. The AR system may have been confusing, since the AR system display different AR content at different distances from target. Or maybe the test procedure was unclear, or the instructions in the testing procedure were confusing. The test persons may also have a bad interaction with the stick, computer or live video-feed from the camera. Many factors could play a role on the ability of having a great overview of the operation.*

One test person strongly agree that the AR system *provided the test person with too much information. Some of the AR components are maybe unnecessary, creating an information flow that is unnecessary. The "Hole detected!" alert is maybe unnecessary, given that the test person could easily locate the hole without this alert. The positioning panel may be more in the way than helping, creating information that is not needed. Another reason the test person is answering this statement in such a negative manner could be since this is the only question negatively formatted towards the AR system. The test person may have read the question wrong, and misunderstood the statement going on "autopilot" through the evaluation answering positively on every task.* The validation of the results will be evaluated in the *Discussion* chapter.

The "Hole detected!" alert is designed to easier locate the hole at the fish cage net. From the results in Figure 5.24, the evaluation of this AR component is mixed. The test

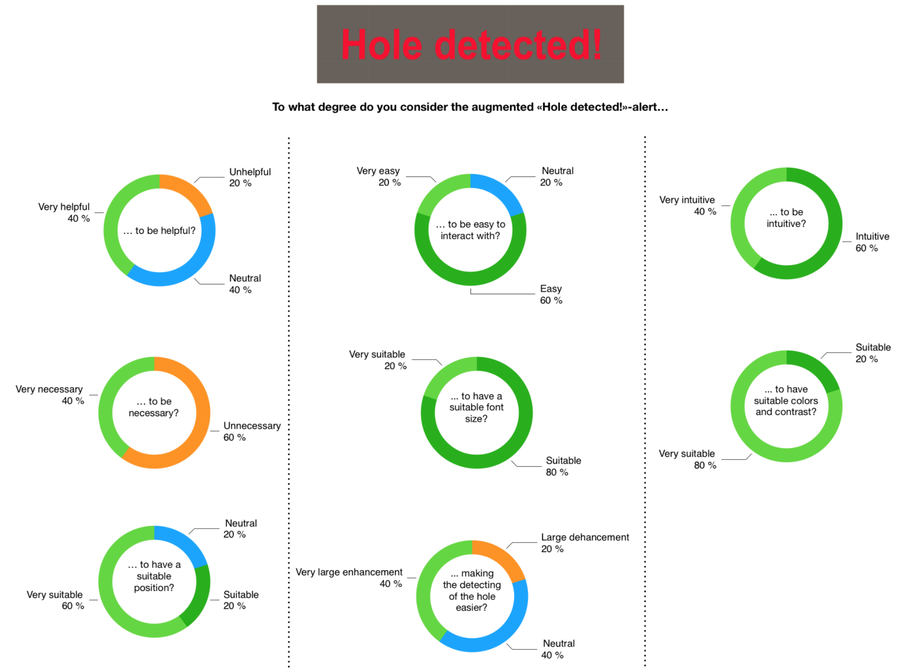


Figure 5.24: The evaluation of the AR component *"Hole detected!" alert.*

persons are positive to the alert being intuitive and easy to interact with. The design of the component is also suitable, where the font size, color and contrast and position get overall positive reviews. The alert is written in big, red colors and the position of the alert is in front of the hole, making it easy to locate the holes position. In the category of helpfulness, one out of the test persons means that the alert is unhelpful. *This is understandable, because the hole could easily be located without the alert, through the AR framer marker surrounding the hole. Hence, the test person thinks that the alert is not very helpful detecting the holes. This is further emphasized in the category asking if the component is necessary, where three out of five test persons answers unnecessary. This is a clear indication that the alert is not necessary to complete the tasks, and is more in the way than helping. That being said, the alert would maybe have been more helpful and necessary if the AR system was not marker-based but markerless. With a markerless AR system there would not have been any markers showing the position of the hole, hence a detection alert would have been more suitable.*

The last question asks if the alert is making it easier to detect the hole. While two of the test persons are satisfied, one of the test persons means the alert is a dehancement to detect the holes easier. Two of the test persons answers neutral on this question.

From the evaluation, it looks like the overall opinion of the alert, is that it is more unnecessary than helping. The test persons could have located the holes easily without the *alert. And then the extra help is not needed, but suits more like a distraction.*

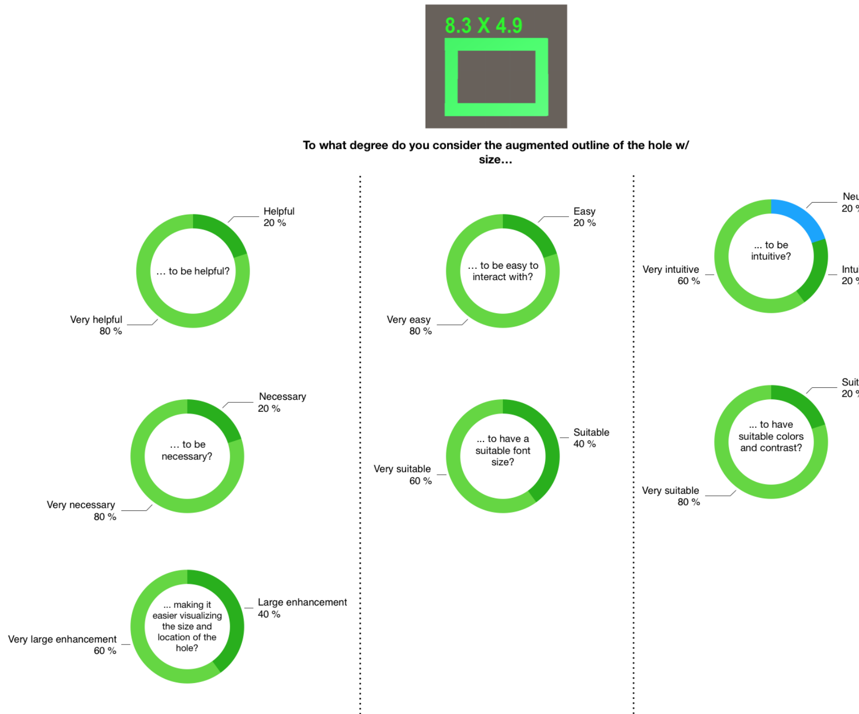


Figure 5.25: The evaluation of the AR component *Outline of hole with size*.

The results of the evaluation of the AR component showing the outline, and the size, of the hole approaching the AR frame marker further, is shown in Figure 5.25. This is one of the AR components with the most positive reviews. The AR components have either positive or very positive response in all categories related to design, usability and function, except in the category *intuitiveness* where one have answered *neutral*. The AR component is crucial in solving the tasks in this experiment, since it indicated which marker with net to attach to fix the hole through the color code of the outline. This makes the AR component highly helpful, intuitive and necessary to complete the tasks.

The AR component is easy to interact with, since it shows relevant information about the hole in an easy way. The font size ensures great readability, emphasizes from the reviews of the test persons. The color of each outline is in bright colors, achieving great contrasting from the environment. The achievement of the main goal of the outline is measured in the last question given to the test persons. The response is exclusively positive, where the test persons means that the outline is making a large or very large enhancement making it easier visualizing the size and location of the hole. *This is an expected result* *since the AR component have been proven to be helpful, necessary, intuitive, easy to interact with and having a suitable design to achieve the purposed function of the component. One possible enhancement would be to add measurement units to the size text, making the size of the hole completely clear.*

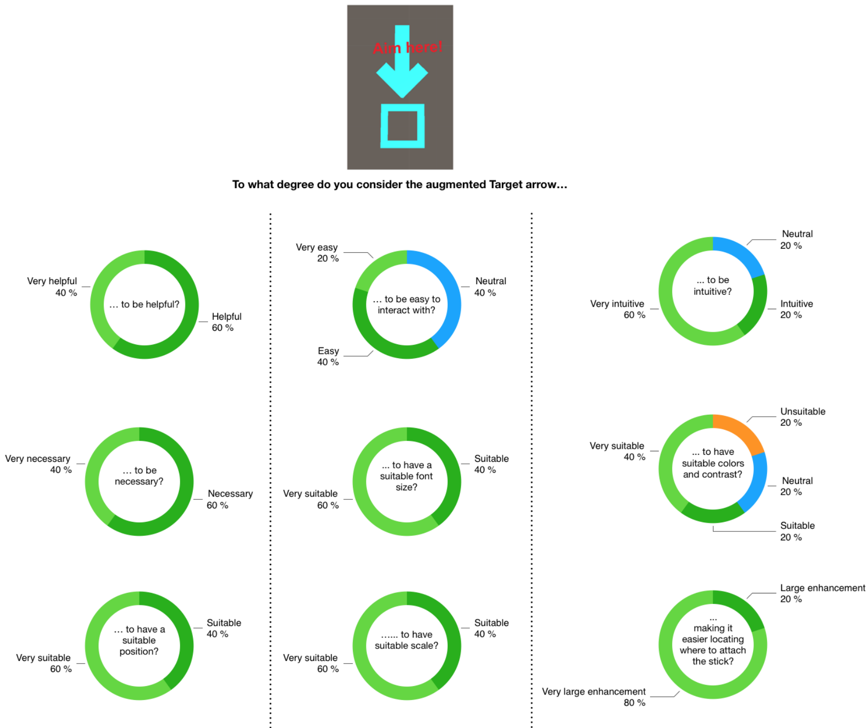


Figure 5.26: The evaluation of the AR component *Target arrow*.

The target arrow is an AR component indicating where to attach the stick to the different attachments in the scene. From Figure 5.26, one can see that the response is positive in the different categories for this AR component. The AR component is considered highly helpful and necessary. The component is also considered easy to interact with and intuitive by most of the test persons. *This is understandable, since the AR component is directly helping the test person attaching the stick to the right locations in the test scene.* Some of the test persons were answering *Neutral* in this category. The text is reviewed as suitable regarding font size, indicating that the text is big enough to clearly show the instruction. The position and scale are also suitable, revealing that the AR component is easy to be seen during operation.

In the category evaluating the color and contrasts of the target arrow, the response is more mixed. Three out of five were positive, while the last two test person were either neutral or meant that the color and contrast of the component was unsuitable. *This could be reassured of personal preferences, not liking the colors being used. The turquoise color* *could be very "flashy" making the AR component hard to look at. The combination of the colors with red text and turquoise arrow and square could be a combination that is not suitable and could be enhanced with a color combination that is more appropriate. Regarding the contrast, maybe the test person did not see the AR component clearly enough during operation or that the contrasting did not fit well with the surrounding in some way. Nevertheless, the turquoise color is not well suited for underwater operations where the surrounding often are highly blue or green, and must therefore be changed to work well in such operations.*

The last category is evaluating the main goal of the AR component, *is the Target arrow making it easier locating where to attach the stick?*. The response here is very positive, with four out of five answering that the Target arrow is a very large enhancement in locating where to attach the stick in the test scene. Hence, the function of the Target arrow is achieving what it is supposed to and the main goal of the AR component is reached. *One of the test person commented that the range of the visibility of the Target arrow should be larger. The test person meant that the target arrow should be seen even closer to the target, instead of showing the support to the positioning, since the target arrow showed the exact location of where to attach the stick. The positioning panel is located over the location of where to attach the stick, to hinder occlusion. The importance of showing the Target arrow rather than the positioning panel, were higher according to the test persons, and this is a possible enhancement of the system that could be made.*

The depth indicators were designed to show the distance to the target in an informative way. From the results in Figure 5.27, this could be seen as one of the most "controversial" AR components in this experiment. The results are very variable in almost all categories, ranging from test persons that are very satisfied with the component, to test persons that do not like the function and design of the component at all. From the observations and screen recordings, it looks like this component is not actively used in most cases. Another factor, is that the depth indicators are not placed optimal.

An optimal position would have been with the location of the attachment in the center of the depth indicators. Before running the experiments, the position with the attachment in the middle of the depth indicators were tested. The big problem locating the depth indicators in such way, was that occlusion occurred. The end of the stick were hidden behind the squares of the depth indicators, when approaching the attachment, causing the indicators to be more in the way than helping. The position chosen for this AR component could be confusing and un-intuitive for the end user. The reasons mentioned above could all contribute to the dissatisfaction of some of the test persons in the question related to *helpfulness*, *intuitiveness*, *necessity* and the question evaluating the position of the component.

Four out of five test persons answered *neutral* on the question asking if the AR component were easy to interact with. *This indicates that most of the test persons did not use this AR components actively during testing.* The AR component is evaluated to have suitable colors and contrast. Nevertheless, the colors have to be changed for underwater

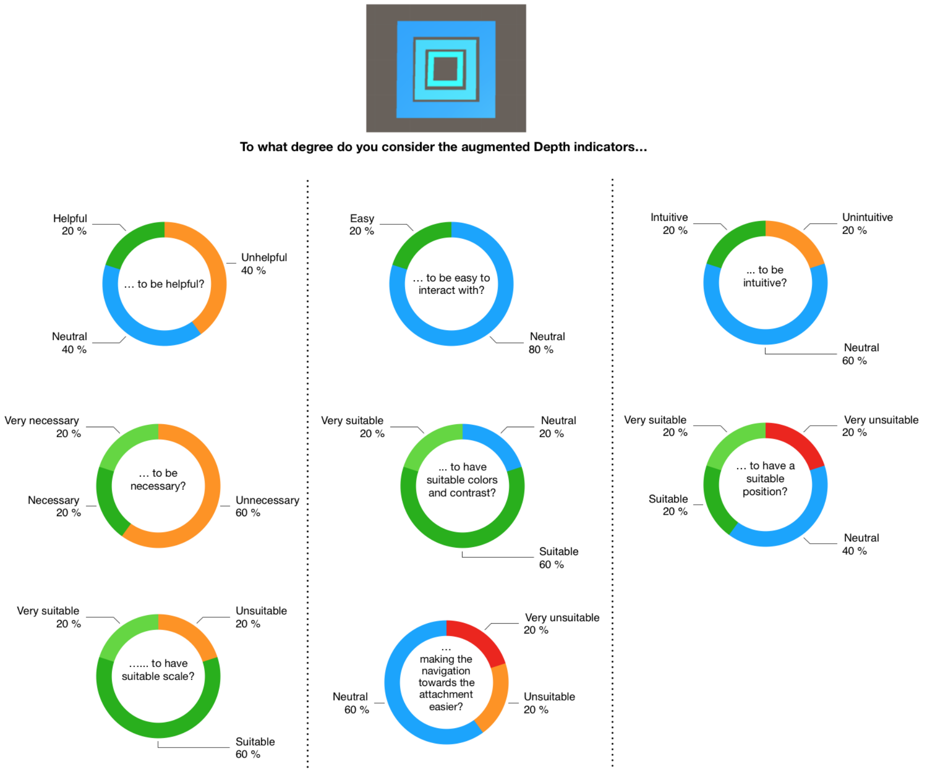


Figure 5.27: The evaluation of the AR components *Depth indicators*.

operations where the environments are different shades of blue. The scale of the depth indicators is considered suitable. One person thinks the scale is unsuitable. The goal of this AR component was to make the navigation towards the attachment easier. From the results(last question) this goal is considered not reached. The response is mostly neutral, and the rest of the test persons think the component is either unsuitable or very unsuitable accomplishing this goal. *The response emphasize the impact of the changed position of the depth indicator to avoid occlusion. With the changed position, the AR components become un-intuitive, and is not used, or is in the way, when completing the tasks in the experiment.*

The correction arrows are meant to correct the path if the user is drifting from the position of the attachment. The response of this AR component is quite positive overall, as shown in Figure 5.28. The correction arrows are considered to be helpful, intuitive, easy to interact with and necessary for competing the tasks. In the three first categories only one test person is unsatisfied with the AR components. *This is in strong contrast to the depth panels, where the response mostly were neutral or negative. The correction arrows are used to complete the tasks. One reason could be that the correction arrows are in front of the test panel, being more prominent. During the experiment, the depth indicators are*

Figure 5.28: The evaluation of the AR components *Correction arrows*.

being ignored while the correction arrows are the AR component of the positioning panel that adds value to the end user.

One of the test persons thinks the position of the correction arrows is very unsuitable. *This could be seen in the context of the position of the rest of the positioning panel which the correction arrows are a part of. As mentioned in the paragraphs above, the position were changed to hinder occlusion of the end of the stick. This position is not optimal, and could be interpreted to be unintuitive and confusing. And this is most probably the reason the test person is not satisfied with the position of the correction arrows.*

The question related to the design of the AR component concerning color and contrasting and the scale of the component is considered either neutral, suitable or very suitable. The size of the arrows and the red color are suitable to get the attention of the test persons and giving the correct instructions. Compared to the depth indicators, the correction is partly achieving the main goal of the AR component, since three out of five persons(60 percent) thinks the correction arrows are very suitable in making the navigation towards the attachment easier. The rest answers *neutral* related to this question. *This result is em-*

phasized by the reasons mention above. The correction arrows are more prominent than the depth indicators, giving instruction to the end user in a better way. And since the correction arrows are in front of the depth arrows, in brighter colors, they get most of the attention when positioning the stick to the attachment. Hence, the correction arrows did a better job guiding the test persons and then achieved the main goal in a better manner than the depth indicators.

5.2.3 Workload: NASA-TLX

The results from the evaluation using the NASA-TLX app during the experiment are presented in this section. The first part will focus on the evaluation of each of the workload factors evaluated in NASA-TLX. The second part will look at the average of the weighted ratings, the overall measure of the workload, for each test person. All the results are analyzed and discussed consecutively.

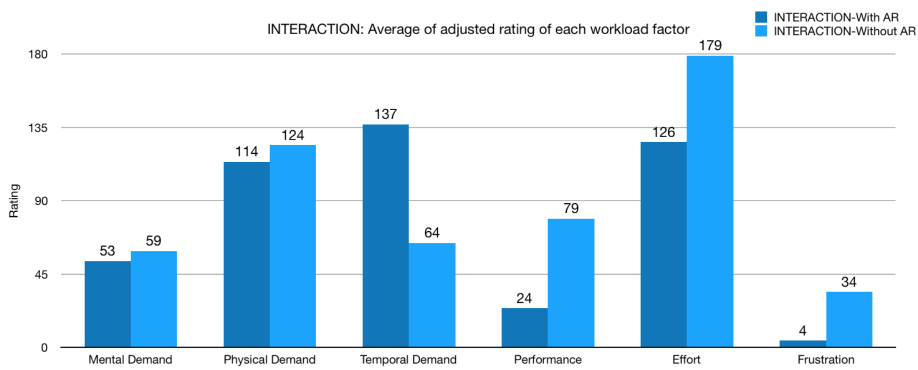


Figure 5.29: The average of the adjusted ratings of each workload factor in the NASA-TLX evaluation.

The different workload factors shown in Figure 5.29, are calculated by multiplying the degree of contribution to the total workload(weights) and the magnitude of the workload of the specific workload factor(ratings). The adjusted ratings give an overall measure of the workload of each of the factors evaluated. From the results in Figure 5.29, one can observed that the factor *Mental Demand* is almost the same for the AR INTERACTION system and the traditional system, with rating of 53 and 59 respectively. The difference is not significant, but the AR system is performing some degrees better than the traditional system. *The factor mental demand is not the factor contributing the most to the overall workload, since the INTERACTION experiment is not especially demanding mentally. To complete the tasks in the experiment, thinking, calculating and remembering lots of data is not needed. The traditional system may score higher in this category, since the test person have to do some calculation and matching using the printed information and framework to find the correct color of the marker with net.*

One of the factors contributing the most to the overall workload is the factor *Physical Demand*, with ratings of 114 and 124 for the AR system and the traditional system respectively. *That the score of both system are high in this factor is no surprise. The interaction experiment is demanding physically, since the test person have to navigate and control the stick throughout the whole experiment. During the testing, the test person did not place the stick in the docking, unlike the INFO experiment, where the stick were placed in the docking many times by some of the test persons. To interact with the stick, some pulling and pushing have to be done doing the inspection of the net. The AR system have some lighter workload in this category, and the reason could be that the whole operation is at the net. With the traditional system, the test person must hold the stick in position, while getting the info from the printed documents at the workstation. This static controlling of the stick while getting the necessary information may cause a little extra physical workload.*

In the factor *Temporal Demand* the workload of the AR system is significantly higher than the traditional system, with rating of 137 and 64 respectively. This means that the test person experienced a higher time pressure, and a pace that was more rapid, using the AR system. *This is a surprising result, since the AR system should basically cause the test person to have a pace that is more calm and controlled. One should think that the AR information could support the test persons, causing the test persons to experience less time pressure. From objective observations, the test persons did not seem stressed by a higher time pressure during the testing of the AR system. The AR components related to the positioning panel could have added time pressure, since they were evaluated to be unintuitive, and hence confusing in the subjective evaluation. Nevertheless, this result is surprising and shows weaknesses and flaws of the AR system implemented.*

With a rating of 24, the AR system has a much lower workload in the factor *Performance* compared to the traditional system with a rating of 79. The test persons were more confident that they successfully have accomplished the task set by the experimenter using the AR system. This also indicates that the test persons were more satisfied with their own performance accomplishing the tasks of the experiment. *An important goal of AR is to make the end user more confident and satisfied when doing a task, by adding supporting information and 3D-overlays. The results here show that the AR INTERACTION system is achieving this, by lowering the workload in the performance category.* The AR system is also performing better related to the factor *Effort* with a rating of 126, compared to the traditional system with a rating of 179. The test person had to work harder, mentally and physically, to accomplish his/her performance using the traditional system compared to the AR system. *This makes sense, since with the traditional system, the test person had to use external data(printed paper at the workstation) to get the necessary information to solve the tasks in the experiment. The operation of getting the information about the holes, matching the info about the hole with the info in the framework to find correct color of marker with net, adds to the workload physically and mentally. Hence, the workload of the effort is higher using the traditional system.*

The last category is the *Frustration* factor, which is the category contributing the least to the overall workload. In this category, the rating is rather modest with the values 4 and 34 for the AR system and traditional system respectively. This indicates that the test persons were not insecure, irritated or frustrated in any way during the experiment, but rather felt secure, relaxed and complacent completing the tasks in the experiment. *It is worth to mention that the rating of both system is low overall, but the difference between the two systems are significant. These differences could be caused by the difference in the testing procedure(using external data versus supplying all the info directly on the test scene using AR). The AR system is accomplishing making the test person feeling confident and satisfied completing the tasks, which is an important goal to achieve for the AR system and the AR technology in general.*

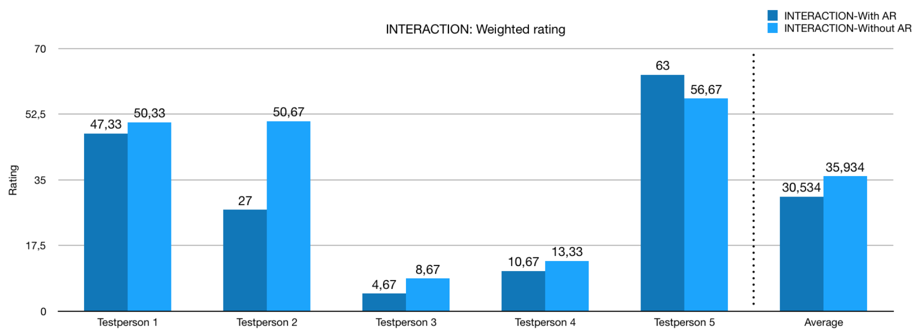


Figure 5.30: The weighted ratings of each test person, and the average of the weighted ratings of all the test persons.

Figure 5.30 shows that the average weighted rating is lower for the AR INTERACTION system than the traditional system. Hence, in total the workload is lower for the AR system compared to the traditional system. *This is not surprising, since the AR system is scoring lower in five out of six workload factors. The factor Temporal Demand is the only factor where the AR system have a higher workload than the traditional system. Through the added AR information, the AR system is giving enough support to lower the workload more than the traditional system.* The workload experienced by the different test person is highly varying. Test person 3 and 4 are experiencing a low overall workload, compared to test person 1, 2 and 5. Test person 2 have the highest difference in ratings between the AR system and traditional system. Test person 5 is the only test person experiencing a higher workload using the AR system compared to the traditional system.

Variation in experienced workload is natural, and is highly dependent on the test persons individual way of working with a specific task. But the trend is definitely that the AR system is the system that have the lowest workload generally when it is operated and used. A factor that may have an impact on the results, is the order of the testing procedure. Each of the test persons in this experiment tried the traditional system first, and then the AR system in the second run. This may have an impact on the workload, since the test person already have experience with the test procedure and inspection of the test wall when the

AR system is tested. It is natural that a procedure is easier the second time completing it. Since the test procedure is quite similar using the AR system and traditional system, the experience the test person has gained in the first run may have an impact. A possible enhancement of the experiment would have been to have half of the test persons to test with the AR system first and the second part to test the traditional system first. This way, the evaluation may have been more fair to both systems, and giving results that are more comparable and valid.

5.3 Proposal of improved AR system

Based on the results and evaluations of the AR systems tested in the project, a concept sketch of an improved system combining the AR INFO system and the AR INTERACTION system is proposed. Based on the findings from the experiments, improvements are proposed and presented. In real-world operations the system could be used in net inspection and repair. Parts of the system, related to the AR, could be transferable to other operations, like fish inspection or mooring inspection and repair. The system presented could be used when trying to detect new net holes, investigate already detected holes or for repair of holes temporary or permanently. The concept of the improved system is assumed to work without markers, using markerless AR. In the future, using markers is not relevant, since placing markers at locations of the aquaculture site is insufficient in operations since it requires extra resources related to time and effort.

The goal of this section is to present an improved system, offer new ideas and inspiration on how to design and implement an AR system that is efficient and simplistic in UID operations in aquaculture. The section will also further discuss findings and experiences from the experiments, related to the improved system.

The improved system have an *inspection mode* and a *repair mode*. The inspection mode is mostly based on the AR components of the AR INFO system, while the repair mode are mostly based on AR components from the AR INTERACTION system. The operator could easily switch between the modes clicking on an UI button on the computer screen displaying the operation.

The ID board used in the AR INFO system and the "Hole detected" alert used in the AR INTERACTION system are removed and replaced with a bounding box in the same colors as the ID Board. The green color of the ID board makes great contrast to the surroundings, making the hole easy to locate. The text indicating the ID is moved to the top left of the bounding box in the new system. This bounding box will instantly pop up when holes are detected, and assign an ID to the hole for later reference(if the hole do not have an ID already). The ID of the hole is instantly saved to a cloud database when detected. This AR component is meant to easily located detected holes at larger distances. The bounding box makes a better overview of the operation. The operator could easily see the hole without anything covering the hole, unlike when using the ID board and "Hole detected!" alert. With the bounding box, the operator could easily locate where the detected hole is, while simultaneously being able to visualize the hole. This is an upgrade from the ID Board, that

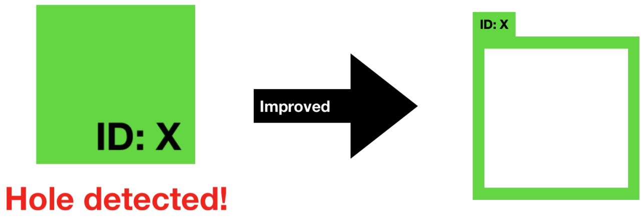


Figure 5.31: The ID board and "Hole detected!" alert are improved using a bounding box with ID to show the location of the hole detected.

covers the hole, and the alert from the interaction system, which only indicate that a hole is detected, and give no accurate information of the location of the hole or the ID of the hole for further reference. The bounding box is used in both inspection and repair mode.

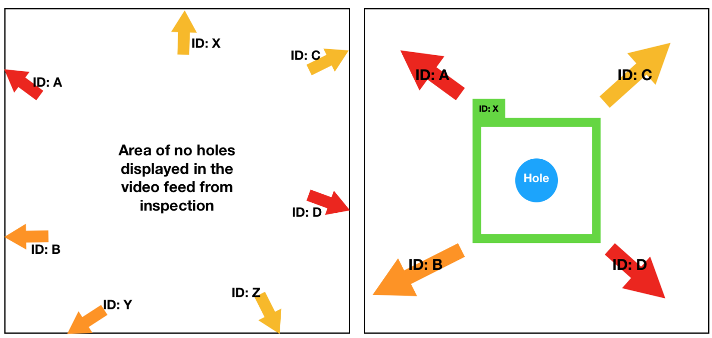


Figure 5.32: The configuration of the arrows with IDs in the improved system. Arrows appear close to the video frame when no holes are showing in the video feed from the operation.

The arrows with ID used in the AR INFO system received very good feedback in the evaluation, so they have not been changed in function and design in the new system. These arrows are optimal used to navigate the operator to (nearby) holes already detected. In the new system, the arrows are also showing as smaller arrows closer to the video frame when no hole is shown in the video feed. Then, the arrows will help navigating on a larger area, and always make indications where the holes are located regardless if any holes are showing in the video frame of the operation. The arrows with ID are shown in both inspection and repair mode. Another AR component receiving great feedback, in both of the experiments, was the outline of the holes with size text. Hence, the configuration of this AR component is not changed. The green color of the outline will still be used in the improved system, since it ensures great contrast to the environments. In the new system, the outline will pop up when a hole is inspected at a closer distance, to accurately visualize the size and location of the hole. In the new system, measurements units are added to the size text to clearly indicate how large the holes are. This AR component is used in both inspection and repair mode, and should be easy to turn completely off so that the operator could do inspections of the hole without the outline on top of it. The size of the hole is directly sent to a database in the cloud so that personnel could analyze the data after inspection.

The status board was an AR components that received a mixed response in the evaluation. In the new system, the status board pops up when the attributes of the holes are calculated and ready, to help the support personnel what actions to perform. A new line have been added telling the operators when the holes should be fixed based on the attributes of the hole. If the hole located is at the bottom of the net, the hole have to be fixed with professional divers or temporarily with ROVs. Holes at the side of the net could easily be fixed by dragging the net onshore. The status board could give instructions on how the net should be fixed and the estimated time it will take. As mentioned in the *Background and theory* chapter, it could take up to two hours before the divers arrive, and hence the status board could instruct the operator to call for divers immediately when the hole is detected.

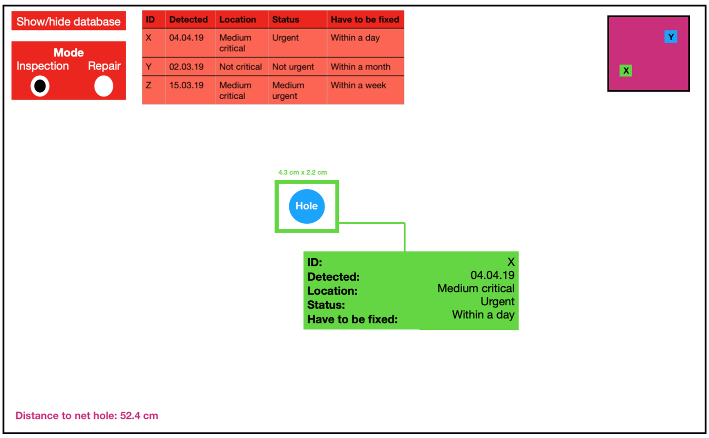


Figure 5.33: Illustration of the video feed at closer inspections of the hole. AR and UI components are showing. The AR content have a green color that is in great contrast to the environment. Static UI components are showed in a violet color. UI buttons are shown in red color. The configuration and presentation of the database are shown in the illustration.

Another color configuration is chosen for the status board in the new system. Instead of using three different colors, two colors are used in the new status board: Black text on green background(the same green color as the outline of the hole). These colors have a high contrast to each other and to the environments underwater, and ensures a consistent design. The status board is quite big, ensuring great readability, and the operator may choose to hide or show the status board using an UI button at the computer screen displaying the video feed from the operation. All the data and attributes calculated and showed in the status board are saved to a cloud database for later reference. In the experiment, the AR INFO system with the status board worked best when performing one-on-one inspections of the hole. Nevertheless, when having to gather data from many different holes at once, the information were not optimal for solving the tasks efficiently. The test persons had to do a lot of extra inspection and checking of the attributes of the holes to get the tasks done. With the new system, the database of already detected and active holes on the net can be shown through an UI panel on the screen in a red color. This enable the operator to do an inspection of a hole, while having the information of all the other holes at the net available. The database could be shown or hidden through a UI button at the screen with the text *"Show/hide database"*. The database offer an overview of important attributes of all the holes at the net in an informative way. Both the status board and database described in this section are only present when the system is in inspection mode.

In the improved system, the "Distance-to-target" bar used in the AR INFO system is not augmented, but rather an UI text showing at the screen when holes are detected. The AR component were meant as a supporting tool to avoid collision. Hence in the experiments, this AR component was either in the way of operation, or not used at all. The UI text will not be in the way of operation, resulting in a better overview of the operation and a more simplistic system with less unnecessary information to handle for the end user. Findings from the experiments show that only AR content that directly help the operator in completing the operation should be used to hinder that the AR system become to complex with to much information. The UI text indicating the distance from target is showing in inspection mode.

The local map of the AR INFO system were designed to show the location of already detected nearby holes on the net. In the INFO experiment, this AR component were not used in a large degree in completing the operation. In the new system, the local map is shown as a UI component in the top right corner of the screen displaying the video feed of the operation. The headline *"Local map"* is removed. The position of the local map is static, but the position of the holes in the local map changes dynamically based on the position of the drone during operation. Hence, the local map is continuously updated to ensure overview of the local situation at the net. The holes shown in the violet map are indicated with IDs, and the color of the current hole shown in the map is changed to the same green color of the outline of the holes when inspecting the holes closer, to ensure great readability of the map in underwater surroundings. Nearby holes are shown in blue. The ID text is in a black color. The local map is showing in both inspection and repair mode, to ensure easier navigation in both operations.

The alert which is part of the AR INFO system, warning that the test person is getting very close to the net to hinder collisions, did only appear two times during the experiment. This is still a necessary component, since it hinder that the drone do collide with the net. From the screen recordings from the experiments, the alert do not have great readability when it is working as an augmented component in the scene. A better solution would be to have the warning as UI text, showing directly on the screen as a warning, instead of dynamically showing it in the scene. The warning should be clear and easily detected, and this is ensured when the warning is showed as UI text over the whole screen of the video stream shown to the operator. The warning is enabled in both inspection and repair mode, since avoiding collisions are crucial in both operations.

The target arrow used in the AR INTERACTION system is set active when the system is in repair mode. The AR component show where attachments are or should be done when repairing the holes. The target arrow could give suggestions on optimal locations to attach the temporary net, so that the location of the temporary net is optimally fixing the net hole. Through the positive feedback of this component in the evaluation, a component of this type could help the operator to navigate the drone to efficiently complete the net repair. The new arrow will be shown in a green color, to ensure great contrast to underwater environments and keep consistency with the colors of the rest of the AR system.

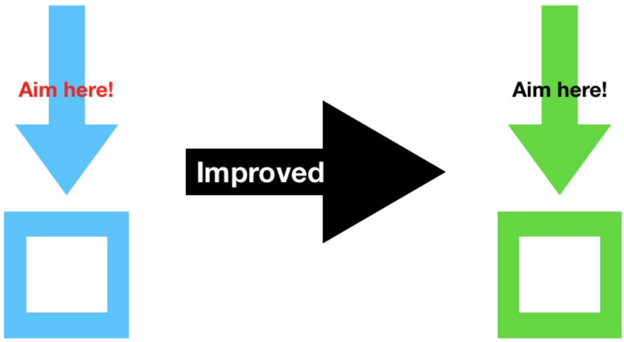


Figure 5.34: The color configuration of the target arrow have been improved, to offer greater contrast and readability.

The AR component the most test persons were dissatisfied with was the depth indicators that were a part of the AR INTERACTION system. The indicators were not particularly used in the operation, and the test persons meant that the component were unsuitable and un-intuitive. The main reason for this is that the depth indicators had a position that were not intuitive. In the improved system, the depth indicators would be on top of the exact location of the attachment. The indicators are shown close to the targets location, about 10-20 centimeters away, giving support in the last part of the operation of repairing the net hole. The optimal use of this component would be to have the indicators placed in such way that the attachment is in the middle of the inner square of the depth indicators. To have such a position and configuration, the challenge of occlusion has to be fixed. The end of the stick, or the manipulator on a drone, could easily be hidden behind the AR content making it impossible to achieve suitable navigation support. The challenge of occlusion is yet not solved, and is a hard task to achieve in such complex and dynamic environments such as an underwater scene at an aquaculture site. If occlusion is fixed, this component would be highly intuitive guiding the operator in repair operations. Another option is to just have the information shown as UI text, the same way as the ”Distance-to-target” bar was modified in the new system. If the depth indicators are being used, the color of the indicators should be changed to different shades of green to ensure great contrast to the underwater environments, and to have consistency with the colors of the rest of the AR system.

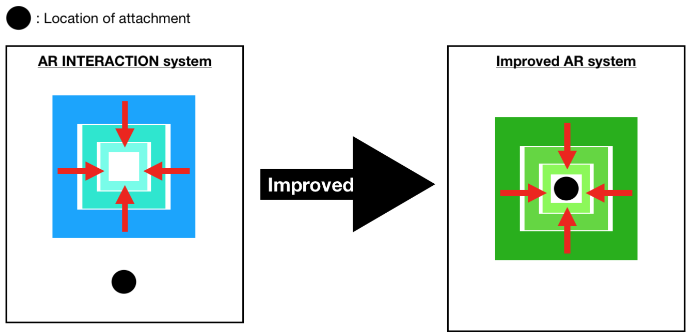


Figure 5.35: The new configuration of the positioning panel is more intuitive having the location of the attachment in the middle of the guiding panel.

The correction arrows, that were a part of the AR INTERACTION system, received good response in the evaluation of the AR components. The design and function of the component, guiding the test persons to completing the correct path to the attachment, are used with the same configuration in the improved system. The only difference would be the position of the correction arrows, that would be changed in the same way as the depth indicators. The arrows will then point to the exact location of the attachment. Again, here the problem of occlusion appear, and have to be fixed if the correction arrows are going to work in the most intuitive way possible. The correction arrows will be shown on top of the depth indicators if the operator is deviating from the suggested path to the attachment. Depth indicators and correction arrows are AR components that are enabled in repair mode only.

Chapter 6

Discussion

In this chapter, relevant topics and broader discussion related to the experiments and the use of AR in aquaculture are being discussed and presented. This chapter covers all discussion of relevance that were not discussed in the *Results* chapter. Theory concerning *confirmation* and *anchoring bias* are presented briefly to give the reader an easier time understanding how the different kinds of biases impacted the results.

6.1 Experiments and validity of results

In this project, two AR systems related to net inspection and repair in aquaculture have been successfully implemented and tested through experiments with a set of test persons. The goals of the thesis could be assumed to be reached. Both AR systems implemented, have been tested up against a benchmark consisting of a system containing no AR. Data and evaluation from the test persons have created a basis for the proposal of an improved AR system, that could be further tested for drone operations in aquaculture. In former chapters, detailed descriptions of both AR systems and experiments are presented to give other engineers and designers ideas and inspiration on how experiments related to AR in aquaculture could be created. In the next sections, a broader discussion will be elaborated, on how AR could enhance drone operations in aquaculture the best way. Hence, the goals of the thesis have been accomplished.

In the project, different tools and types of evaluations have been used to implement and evaluate the AR systems. To implement the AR systems, the game-editor Unity with the AR library Vuforia were used. All the scripts were made in Visual Studio. The developer platform were easy to use, and offered powerful tools to efficiently create marker-based AR systems. The integration between Unity and Visual Studio made it easy to script the correct functioning to each AR component designed in the Unity editor. The user interface did also make it easy to switch between different scenes in the editor associated to the different systems used in the experiment. During testing, switching between the systems happened efficiently, and the user interface of the Unity editor enabled this.

To evaluate the workload using each system, the NASA-TLX app were used. Using this app, the workload were efficiently evaluated. While the experimenter changed the configuration of the test scene in between testing the various systems, the test persons were conducting the evaluation on the app. Evaluating the workload this way, resulted in fast and time efficient evaluation of the AR systems. One test person pointed out that the instructions in the app were hard to remember while conducting the evaluation, since the instructions of the procedure were mention only in the beginning of the evaluation. This could have impacted the results, resulting in inaccurate measures of the workload if the test persons did not remember what each question entailed while answering the survey. A more closely guiding by the experimenter, while the test persons conducted the survey, would have ensured more accurate results since the test persons could have more easily asked if something was unclear while conducting the survey. Instead, the experimenter were busy changing the configuration of the test scene. Nevertheless, the experimenter was available at all times for questions related to the NASA-TLX evaluation.

The subjective evaluations of the AR systems were conducted through Google Forms after the experiments. Creating forms and receiving results from the test persons were efficient and easy using Google Form. Using this platform, the results and data were sufficiently saved in the cloud, ensuring that no data are lost. The subjective evaluation contained questions that seemed covering for evaluating the performance and user interface of the AR systems, based on the usability goals defined and described in the *Theory and background* chapter. Some of the test persons indicated that some of the questions were very similar, and that the test persons had to focus to see the different shade of the questions and what they evaluated and entailed. This could lead to inaccurate results, and could have been avoided creating more clearly defined questions. Supporting descriptions of each questions could also have been made, to clearly show what each question entailed and evaluated.

The way the questions in the subjective evaluation were asked, could have been more optimally formulated. Almost all the questions in the evaluation is on the form ”How did the AR system perform in category A compared to the traditional system?”. The questions should have been formulated in different ways ensuring that the test persons is not answering in favor of one of the systems by default. The way the questions were formulated, may have been caused by *confirmation bias*. *Confirmation bias appear when the experimenter unconsciously reference to only those perspectives that fuel the pre-existing views, while at the same time ignoring or dismissing opinions that threatens the world view of the experimenter, no matter how valid[55].* The wanted results, such that the AR systems performed better than the systems without AR, may have subconsciously made the questions formulated in such way that they are not fair towards both systems.

An example is that the system without AR is called ”Traditional system”, which may not be a suitable name of the system. A ”traditional system” may sound like a conservative, less innovative and old system, causing *anchoring bias* in the answering of the questions and before testing the system. *Anchoring bias appear when humans relay to heavily on the* *first information offered when making a decision[55].* That the test persons may have an impression of the ”traditional system” to be less provident, before testing, this may have caused an ”anchor” in the testing and evaluation of the traditional system. The name of the system should have been changed to ”system without AR”, to be more equated to the AR system. The questions should have been formulated in a more neutral way, and the order of what system is mentioned first in the questions should have been mixed for each new questions ensuring that the test persons is answering more accurately to each question.

During the experiments, screen recordings of the computer screen used in the experiment and objective observations were conducted. The screen recording made it easy to collect results after the experiments were finished, such as the metric *completion time of tasks*. Objective observations were made to observe the test person completing the experiment. Reactions and comments during testing were important in creating a basis for further analysis and discussion of the performance and usability of the AR systems.

The method chosen, comparing the AR system up against a system without AR, have been suitable for evaluating the performance of the AR system. Using a benchmark with the system without AR, makes it easy to identify where the AR systems performs better or worse than a system without AR, and the concept of the improved system could be created through these findings. The experiment setup worked well during the experiments, but the stick with the camera was hard to operate for some of the test persons. Some of the test persons had a hard time moving the stick with the camera towards and away from the targets at the net. This may have impacted the variance of the completion times between the test persons. From observations, the results isolated for each test persons is not impacted by this problem.

When testing the systems, the test scene without AR is always tested first in both experiments. This could have an impact on the completion time, since the test person is more experienced with both hardware of the experiment setup and software of the systems after testing the system without AR. This experience may have been to good help when testing the AR system afterwards, and may have given results that are better than if the AR system have been tested isolated, without any experience of hardware and software beforehand. By changing the order of the test procedure for each test person, alternating between testing the system with and without AR first, may have given more valid data since the impact of the order could have been analyzed and taken into account when analyzing the results from the experiments. Another factor that could have increased the validity of the results, would have been to increase the number and diversity of the test persons. With five test persons, with almost the same age and educational background, the data from this experiments are not the most diversified. Operators in real-world operations are trained professionals, but factors like age, health and professional background may have an impact when learning new technology like AR. Hence, having a larger and more diversified set of test persons could potentially lead to a more thorough evaluation of the AR systems.

6.2 How could AR enhance operations in aquaculture?

The experiments have shown that AR could potentially enhance support in drone operations in aquaculture in a number of ways. Based on the completion times in the one-on-one inspections of the INFO experiment and the completions times of the INTERACTION experiment, the AR system have achieved to save time completing the some operations. AR have shown great potential in supporting repair operations, which could be used by both drones and professional divers(using head-up-displays). Today, professional divers perform the complex task of repairing the holes at difficult locations of the net, by sewing the holes so that they are fixed permanently. In the future, drone may do repair operations of the net without interference with professional divers. To achieve this, AR may be an important component providing necessary information and support. AR could play a critical part in positioning and navigating the robotic arm in the sewing process, using AR information in such form like the positioning panel of the AR INTERACTION system. Using only drones in such operations will increase safety and reduce cost, and contribute to a more efficient maintenance of the aquaculture site.

Through added 3D-info, the operations underwater could be completed easier and more accurately. The correction arrows that are parts of the AR INTERACTION system have shown to provide great guidance during operation. Such AR components could make it much easier for support personnel to navigate the drone. AR components like the corrections arrow could also be used to monitor the thought process of autonomous drone, showing what kind of operations the drone is doing next. If the drone is doing something unexpected(corrections arrows are showing that the drone is drifting from correct path), the personnel could interfere by steering the drone manually until the system is fixed. This is related to the issue of how much the operator should depend on the AR system in supporting the operation. The AR system presented in such operations must be highly accurate to avoid collisions and destruction of equipment. The AR technology can not make the operator personnel ”lazy”, only assuming that the AR is working perfectly all the time. The personnel should be critical during operations, and be ready to interfere with the operation if anything unexpected and unsuitable happens. Nevertheless, the AR system could help creating more safety through warnings that the drone is getting close to the net, or to show the proposed path by the autonomous drone to get a better overview of the operation. Like in autonomous cars today, where the drive must actively monitor the cars response and be ready to interfere if something unexpected happens, the personnel at an aquaculture site must do the same during manual or autonomous ROV operations.

Another issue related to the use of AR is how the data should be handled. In the experiments, observations indicated an overflow of information to the test persons, resulting in increased completion time of the set of tasks. The personnel should be able to enable different kinds of AR info related to the operation performed. In the improved system proposed, two different kind of modes are introduced; inspection and repair mode. These two operations are different, and requires different types of data. The overflow of information seen in the experiments, could have been solved using a database shown in the suggested, improved AR system. The personnel could enable and disable the database by the click of a button. Since such AR components or UI text would cover most of the screen, the personnel should be able to hide the database. By displaying the database, the personnel have the availability to get a full overview of the holes at the net, while monitoring the inspection of the current holes investigated. A great example of AR displaying information when and where it is needed is the status board of the AR INFO system. The status board shows the most important attributes of the hole, necessary to take sufficient action, avoiding giving the test persons too much information. The info of the status board could easily be transported to a cloud interface, where the data is saved to a database. Then the data is safely saved and easily accessed when the hole is detected again or if the personnel want to analyze the entire database during or after operation.

The improved system proposed would potentially make a big improvement, creating a complete system for both inspection and repair of the net holes. From the findings in the experiments, a simplistic AR system showing only the most necessary data needed to complete the operation, is the correct way to design an AR system in aquaculture. Supporting AR elements such as the "Distance-to-target" bar or local map were in most cases not used at all to complete the operations, compared to directly involved components such as the status board, corrections arrows or the outline of the holes with size text. Hence, it is crucial that the AR adds value to the operation directly. Supporting components should be shown as static UI text at the computer screen, instead of augmented components in the scene. A more simplistic AR user interface have the advantage that not so much information of the net is hidden underneath the AR information. A suggestion is that all the AR information could be enabled and disabled during inspection. If the test person is suspicious that some important information is hidden beneath the AR information, the AR could be disabled for closer investigation. This is also suitable in situation where the AR may operate insufficiently and have to be turned off. Hence, the best way to hinder that AR is not covering anything of importance, is to create an AR system that is simplistic, yet informative enough to support and help completing the operation.

Testing and performing AR underwater are faced with many obstacles and challenges, elaborated in Chapter 2.4.2. Light conditions underwater are challenging, caused by effects like refraction, light absorption and colors absorption. Refraction is a complex challenge to handle, since the objects appearing 25 percent larger and closer due to the light traveling through the camera lens, would make it hard to establish a correct and accurate pose of the AR components in the scene. To solve this problem, advanced techniques related to camera calibration must be performed, to adapt the necessary camera parameters to the underwater environment. Lights and color absorption makes it hard to accomplish tasks further down in the fish cage, due to less light and colors distributed. To solve this issue, artificial light could be used, but artificial light could cause the AR system to fail since high turbidity in the water could cause a high degree of reflections and undistributed light. Since drone operations are most relevant to use in operations further down the fish cage, this is an issue that most be solved sufficiently if autonomous operations with AR could be achieved.

Another issue related to AR is occlusion. Occlusion appeared in the testing of the AR INTERACTION system, resulting in that the position panel had to be moved in an insufficient position. Occlusion, where real-world objects are hidden behind the AR content, must be avoided by either solving the problem using complex software or use methods to avoid most situations where occlusion may occur. In such a dynamic environment like a fish cage in aquaculture, the need to properly handle occlusion is present. One way to solve this issue is to not design and implement AR content that may interfere with the manipulator of the drone or external objects. AR components could be designed such way that they operate optimal while not being in the way of operation. The positioning panel in the AR INTERACTION system could be implemented such way that it is intuitive while at the same time not being in the way. Fish or other dynamic objects could make problems for the AR system, hiding necessary features making it hard for the computer vision detecting key points needed to display AR info. This could be solved partly by performing the inspection of the net while the fish are fed properly and act calm. Another option is to put the operations at hold, while the fish are moving in front of the drone, and continue when the fish are gone from the scene. While this is an option that could increase cost and time consumed, it is an option that ensures that the operation is completed. All the issues mentioned above must be solved before having a fully robust and advanced AR system providing enhanced support of drone operations doing net inspection and repair in aquaculture.

Chapter 7

Conclusion and further work

Through this project, AR have shown to be a promising technology based on the evaluations conducted. The AR system were successfully implemented using Unity with the AR library Vuforia, and the AR systems worked in a robust and accurate way throughout the experiments. The function and design of the AR systems were suitable for investigating how AR could benefit the operation of net inspection and repair at aquaculture sites. The AR systems showed promising result in one-on-one inspection, gathering and working with information from one individual net hole at the time. When info had to be gathered from several holes at the same time, to solve the set of tasks, the test persons experienced an information overload causing the performance of the AR systems to decrease. A database consisting of info about all the holes at the net, may have solved the problem with information overload, and hence were included as a part of the proposal of an improved AR system. In the INTERACTION experiment, the AR INTERACTION system showed promising results adding depth perception and 3D-information in positioning the stick to fix the net holes in the test scene. The AR INTERACTION system saved time in the operation and the test persons experienced a decrease in workload compared to the system without AR.

Both AR systems were successfully tested and evaluated through the INFO and INTERACTION experiments. Using a system without AR were a suitable benchmark to evaluated the performance, workload and usability of the AR systems. Workload were easily measured using the NASA-TLX app, and the subjective evaluation gave a detailed evaluation of the AR systems and the individual AR components of the systems. In the subjective evaluation, the validation of the results have been discussed, and cases of certain biases may have made an impact in favor of the AR systems. These biases are pointed out, so that they are avoided in similar experiments conducted in the future. Screen recordings and objective observations were methods that worked well in gathering and analyzing results from the experiments.

The thesis have shown that AR could play a critical role in saving time, reducing cost and enhancing both depth perception and decision support during operations of net inspection and repair. The depth perception could be further improved when occlusion is solved, so that the positioning panel of the AR INTERACTION system could be located such that the center of the panel is at the location of the attachment. The AR systems showed better performance related to completion times, usability and workload in most parts of the experiments conducted. The kind of AR content that enhanced the completion of the operation, were AR content that contributed directly to the operation. These components were providing important information, like the status board, or helped directly related to the interaction in the test scene, like the correction arrows. Elements that are not contributing directly to performing the operation should not be augmented, but be static UI components at the computer screen. Examples here are the ”Distance-to-target” bar or the local map, suiting as supporting elements in the navigation.

This thesis concludes that the best way to use AR related to net inspections and repair, is to use a simplistic system that only display the most necessary AR content to better depth perception and decisions support. The benefits of utilizing AR are not present if to much information is introduced to the operator. The AR content have to be adapted to the operation that is performed. The operator should be able to switch between different AR modes, to make a flexible system that could be used for both inspection and repair of the net holes. The operator should also be able to entirely turn off the AR if the operator is suspicious that something of importance is hidden under the AR content. All these aspects have been elaborated in the *Discussion* chapter, where new ideas and insight have been given to potentially progress the work of other researchers doing similar projects.

The overall conclusion is that AR is a promising technology that could give great benefits related to operations of net inspection and repair when utilized. The technology have the potential to save time, reduce cost, decrease workload, better depth perception and add decision support to operations. The upside of using this technology is clear, but further implementations and testing have to be done until achieving a fully functional and robust AR system that can be used for ROV operations performing net inspections and repair at aquaculture sites.

Through future research, hopefully the AR systems implemented in this thesis could be improved upon with added functionality, that further could enhance operations related to net inspection and repair. The following list presents suggestions for further testing and research of AR related to aquaculture:

- Encoding AR content to AR markers in the method of marker-based AR is an efficient method to implement and test AR. Using marker based AR, AR systems could be tested and evaluated in a rapid way in categories such as usability and performance. Using markers offers many benefits, elaborated in Chapter 2.3.2. Fast upgrades and changes can be made to efficiently progress the testing of the AR systems. In the future, utilizing markerless AR is the ultimate goal, but marker-based AR is suitable to rapidly testing and evaluating the user interface of the AR systems. AR markers are easy to work with, and could easily be attached to the net using waterproof clips.

- Evaluating the AR system towards a benchmark using a system without AR, performing the same set of structured tasks, is a good way of evaluating if the AR system is adding value to the operations conducted. The structured tasks could be defined to test specific aspects of the AR system, or to evaluate a large range of functions of the AR system.

- Challenges related to handling light conditions and weather conditions have to be solved or worked around to ensure a robust and reliable AR system used in challenging underwater environments. The problem of occlusion must be solved or worked around, to handle the dynamic objects, like fish, and to accurately display AR content.

- Using the NASA-TLX app to evaluate workload of a specific task is both flexible and easy. The test person just receives the smart phone and complete a survey on the app, and this could be done to evaluate segments of a task or an entire task. After the experience from the use of this app in this thesis, the method is recommended when evaluating the workload of a task related to using AR.

- If AR systems are being tested over water, related to ROV operations in aquaculture, it would be better to attach the camera to a robotic arm to create a more realistic setup related to ROV operations.

- Underwater testing of AR related to aquaculture must be performed, and adjustments of the AR systems must be done to achieve this. One idea is to test the AR system in onshore water tanks. Then the AR system could be tested in calm water avoiding rough weather conditions, but still testing the AR in challenging environments related to light conditions. This is a good way to begin testing of AR underwater, and could be further built upon.

- For future experiments, it is recommended to use a higher number of test persons when conducting the experiments. AR technology is very user oriented, and should be thoroughly tested with a large set of operators to make sure that the AR is working properly related to performance, accuracy and usability.

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Appendix A

Code listings

A.1 Code listings: AR INFO system

In the Listing A.1 an example of a C# script configuring the function of the AR INFO system when one of the AR frame markers are detected in the test scene, are presented. The script indicate how the configuration of displaying different AR components at different distances from the AR frame marker is implemented. The example here shows the configuration of the displaying the AR content when the AR frame marker *MarkerY1* is detected. A script is created for each AR frame marker ranging from *MarkerY1* to *MarkerY5*(since there are five AR frame markers in the test scene).

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using System.Globalization;

public class MarkerY1_config : MonoBehaviour
{
    // The MarkerY1 is defined as a Transform used to calculate pose of
    marker
    public Transform MarkerY1;

    // Float defined to store the distance between the camera and AR
    marker
    public float distanceY1;

    // The game objects of the ID Board and Statusboard are defined
    public GameObject indicator_Y1;
    public GameObject statusBoard_Y1;


    // The game object of the "Distance-to-target" bar is defined
    public GameObject distance_to_target_Y1;
    public GameObject distIndicator_30;
    public GameObject distIndicator_15;
    public GameObject distIndicator_0;
```

```
    public GameObject distance1_Y1;
    public GameObject distance2_Y1;
    public GameObject distance3_Y1;
    public GameObject distance4_Y1;
    public GameObject distance5_Y1;
    public GameObject distance6_Y1;
    public GameObject distance7_Y1;
    public GameObject distance8_Y1;
    public GameObject distance9_Y1;
    public GameObject distance10_Y1;
    public GameObject distance11_Y1;
    public GameObject distance12_Y1;


    // The game objects of the local map, alert,
    // arrows with ID and outline with size are defined
    public GameObject local_map_Y1;
    public GameObject alert_Y1;
    public GameObject arrow_Y1;
    public GameObject hole_size_Y1;


    void Start()
    {
        // The class is initilized from the Start() function
    }


    // Update is called once per frame
    void Update()
    {
        if (MarkerY1)
        {
            // Distance between camera and AR marker is calculated
            distanceY1 = Vector3.Distance(MarkerY1.transform.position, transform.position);

            // All game objects except the ID Board are not active at this distance from target
            statusBoard_Y1.SetActive(false);
            local_map_Y1.SetActive(false);

            distance1_Y1.SetActive(false);
            distance2_Y1.SetActive(false);
            distance3_Y1.SetActive(false);
            distance4_Y1.SetActive(false);
            distance5_Y1.SetActive(false);
            distance6_Y1.SetActive(false);
            distance7_Y1.SetActive(false);
            distance8_Y1.SetActive(false);
            distance9_Y1.SetActive(false);
            distance10_Y1.SetActive(false);
            distance11_Y1.SetActive(false);
            distance12_Y1.SetActive(false);

            hole_size_Y1.SetActive(false);
```

```
            alert_Y1.SetActive(false);
            arrow_Y1.SetActive(false);

            distance_to_target_Y1.SetActive(false);
            distIndicator_50.SetActive(false);
            distIndicator_25.SetActive(false);
            distIndicator_0.SetActive(false);

            if (distanceY1 < 40)
            {
                // When distance to target is less than 40 cm,
                // the arrows with ID are set active
                arrow_Y1.SetActive(true);
            }

            if (distanceY1 < 30)
            {

                // At a distance less than 30 cm away from target,
                // the AR components related to the close inspection of the hole are set active.
                // The ID board and arrows with ID are not active at this distance from target.

                local_map_Y1.SetActive(true);
                statusBoard_Y1.SetActive(true);

                distance_to_target_Y1.SetActive(true);
                distIndicator_30.SetActive(true);
                distIndicator_15.SetActive(true);
                distIndicator_0.SetActive(true);

                hole_size_Y1.SetActive(true);

                distance1_Y1.SetActive(true);
                distance2_Y1.SetActive(true);
                distance3_Y1.SetActive(true);
                distance4_Y1.SetActive(true);
                distance5_Y1.SetActive(true);
                distance6_Y1.SetActive(true);
                distance7_Y1.SetActive(true);
                distance8_Y1.SetActive(true);
                distance9_Y1.SetActive(true);
                distance10_Y1.SetActive(true);
                distance11_Y1.SetActive(true);
                distance12_Y1.SetActive(true);


                indicator_Y1.SetActive(false);
                arrow_Y1.SetActive(false);


                // The cubes that are part of the "Distance-to-target" bar
                // disappears/appears when approaching/moving away from the target.
                if (distanceY1 < 27.5)
```

```
            {
                distance1_Y1.SetActive(false);
            }

            if (distanceY1 < 25)
            {
                distance2_Y1.SetActive(false);
            }

            if (distanceY1 < 22.5)
            {
                distance3_Y1.SetActive(false);
            }

            if (distanceY1 < 20)
            {
                distance4_Y1.SetActive(false);
            }

            if (distanceY1 < 17.5)
            {
                distance5_Y1.SetActive(false);
            }

            if (distanceY1 < 15)
            {
                distance6_Y1.SetActive(false);
            }

            if (distanceY1 < 12.5)
            {
                distance7_Y1.SetActive(false);
            }

            if (distanceY1 < 10)
            {
                distance8_Y1.SetActive(false);
                alert_Y1.SetActive(true);
            }

            if (distanceY1 < 7.5)
            {
                distance9_Y1.SetActive(false);
            }

            if (distanceY1 < 5)
            {
                distance10_Y1.SetActive(false);
            }

            if (distanceY1 < 2.5)
            {
                distance11_Y1.SetActive(false);
            }

            if (distanceY1 < 1)
            {
```

```
                    distance12_Y1.SetActive(false);
                }

            }

            else
                // If the distance to target is larger than 40 cm,
                // the ID board is set active.
                indicator_Y1.SetActive(true);
        }
    }
}
```

Listing A.1: C# script used to configure AR content of the AR INFO system.

A.2 Code listings: AR INTERACTION system

In Listing A.2 the configuration of displaying AR content when the AR square marker is detected in the test scene, is shown. The AR square marker display the AR content related to positioning support and depth perception, which is the target arrow, depth indicators and correction arrows.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class SquareMarker_config : MonoBehaviour
{
    // The AR square marker is defined as a Transform used to calculate
    pose of marker
    public Transform squareMarker;

    // Float defined to store the distance between the camera and AR
    marker
    public float distanceToTarget;

    // Floats defined to store the relative position between camera and AR
     marker,
    // in the xy-plane.
    public float positionX;
    public float positionY;

    // The game object of the target arrow is defined
    public GameObject indicatorArrow;

    // The game objects of the depth indicators are defined
    public GameObject square_medium;
    public GameObject square_small;
    public GameObject square_verySmall;


    // The game objects of the correction arrows are defined
    public GameObject arrowUp;
    public GameObject arrowDown;
    public GameObject arrowRight;
```

```
    public GameObject arrowLeft;


    void Start()
    {
        // The class is initialized from the Start() function
    }


    // Update is called once per frame
    void Update()
    {

        if (squareMarker)
        {
            // The distance between the camera and AR square marker is calculated
            distanceToTarget = Vector3.Distance(squareMarker.transform.position, transform.position);

            // The relative positions between the camera and AR square marker in the
            // xy-plane are calculated.
            positionX = transform.position.x - squareMarker.transform.position.x;
            positionY = transform.position.y - squareMarker.transform.position.y;

            // At distances further away than 20 cm away from the
            // AR square marker, the target arrow, depth indicators and
            // correction arrows are set to not be active.
            square_medium.SetActive(false);
            square_small.SetActive(false);
            square_verySmall.SetActive(false);

            indicatorArrow.SetActive(false);

            arrowUp.SetActive(false);
            arrowDown.SetActive(false);
            arrowRight.SetActive(false);
            arrowLeft.SetActive(false);


            if (distanceToTarget < 20)
            {
                // At a distance closer than 20 cm, the target arrow is set active
                indicatorArrow.SetActive(true);
            }

            if (distanceToTarget < 15)
            {

                // At distances closer than 15 cm from AR square marker,
                // the target arrow is set to not active, while the depth indicators
                // are set to active.
```

```
                indicatorArrow.SetActive(false);

                square_medium.SetActive(true);
                square_small.SetActive(true);
                square_verySmall.SetActive(true);


                // The squares that are part of the depth indicators
                // disappears/appears when approaching/moving away from the target.
                if (distanceToTarget < 13)
                {
                    square_medium.SetActive(false);
                }

                if (distanceToTarget < 11.5)
                {
                    square_small.SetActive(false);
                }
                if (distanceToTarget < 9)
                {
                    square_verySmall.SetActive(false);
                }


                // If the relative positions in the xy-plane diverge to much,
                // the correction arrows will be showing to instruct the user
                // in the correct direction to obtain optimal path.
                if (positionX < -0.4)
                {
                    arrowRight.SetActive(true);
                }

                if (positionX > 0.4)
                {
                    arrowLeft.SetActive(true);
                }

                if (positionY < -1)
                {
                    arrowUp.SetActive(true);
                }

                if (positionY > -0.4)
                {
                    arrowDown.SetActive(true);
                }

            }
            else
                indicatorArrow.SetActive(true);
        }

    }
```

```
}
```

Listing A.2: C# script used to configure AR content of the AR INTERACTION system when the AR square marker is detected.

In Listing A.3 the configuration of displaying AR content when a AR frame marker is detected in the test scene, are presented. The AR frame marker is used to display the AR content related to information about the holes, which entail the ”Hole detected!” alert and the outline of the hole with indication of size. In the example C# script the configuration when AR frame marker *MarkerY1* is detected in the test scene is shown. Since there are four holes in the test scene, four scripts are created for each AR frame marker, ranging from *MarkerY1* to *MarkerY4*.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class MarkerY1_setup : MonoBehaviour
{
    // The MarkerY1 is defined as a Transform used to calculate pose of
    marker
    public Transform MarkerY1;

    // Float defined to store the distance between the camera and AR
    marker
    public float distanceToTarget_Y1;

    // The game objects of the "Hole detected!" alert
    // and outline of hole with size text are defined
    public GameObject Hole_detected_Y1;
    public GameObject Hole_size_Y1;


    void Start()
    {
        // The class is initilized from the Start() function
    }

    // Update is called once per frame
    void Update()
    {

        if (MarkerY1)
        {
            // Distance between camera and AR marker is calculated
            distanceToTarget_Y1 = Vector3.Distance(MarkerY1.transform.
    position, transform.position);

            // Outline of hole with size text are not set to active
            // at this distance from the AR marker
            Hole_size_Y1.SetActive(false);

            if (distanceToTarget_Y1 < 30)
            {
                // At distance closer than 30 cm, the
                // "Hole detected!" alert is not active.
```

```
                // The outline of the hole with size text is set to active
    .
                Hole_detected_Y1.SetActive(false);
                Hole_size_Y1.SetActive(true);

                if (distanceToTarget_Y1 < 25)
                {
                    // At a distance closer than 25 cm away from the
                    // AR marker, the outline of the hole with size text
                    // is not set to active.
                    Hole_size_Y1.SetActive(false);
                }
            }
            else
                // At distances larger than 30 cm away from the
                // AR marker, the "Hole detected!" alert is showing
                // if any holes are detected.
                Hole_detected_Y1.SetActive(true);

        }

    }
}
```

Listing A.3: C# script used to configure AR content of the AR INTERACTION system when an AR frame marker is detected.

Appendix B

Subjective evaluations

B.1 INFO experiment: Subjective evaluation

In the following, the *questions and statements* of the subjective evaluation are presented in italic. Behind each question or statement, the **Usability goals** evaluated are written in bold, and the type of question is also indicated. Questions related to the evaluation of the systems used in the INFO experiment only, are written in a red color.

AR system vs traditional system

This section of the evaluation contains statements and questions for evaluating the performance of the AR system compared to the traditional system(with no AR).

The task was easier accomplished using the AR system compared to the traditional system. **Effectiveness** Scale
The tasks were more efficiently solved using the AR system compared to the traditional system. **Effectiveness** Scale
*The holes were easier located and identified with the AR system compared to the traditional system.***Situation awareness** Scale
I felt a greater overview of the operation, and tasks at hand, using the AR system compared to the traditional system. **Situation awareness** Scale
The AR system was more satisfying using than the traditional system. **Satisfaction** Scale
The AR system was more helpful completing the tasks than the traditional system. **Satisfaction** Scale
The AR system increased my productivity compared to the traditional system. **Effectiveness** Scale
The AR system improved the user experience compared to the traditional system. **Satisfaction** Scale
I felt less discomfort and stress using the AR system than the traditional system. **Workload** Scale
The overall workload is smaller using the AR system compared to the traditional system.

Workload Scale

Did the AR system provide faster learning than the traditional system? **Effectiveness** Multiple-choice question
Did the AR system provide better access to the information than the traditional system? **Effectiveness** Multiple-choice question
Did the AR system provide faster gathering of relevant information than the traditional system? **Effectiveness** Multiple-choice question
Do you think that an AR system like this could save time compared to a traditional system without AR? **Effectiveness** Multiple-choice question
Do you think that an AR system like this could improve efficiency compared to a traditional system without AR? **Effectiveness** Multiple-choice question
Do you think that an AR system like this could enhance decision support compared to a traditional system without AR? **Effectiveness** Multiple-choice question

Other comments? Comment

Detailed evaluation of the AR system
This section contain statements and questions for evaluating the performance, design and usability of the AR system.

The AR information was relevant for solving the tasks. **Satisfaction** Scale
The AR system was easy to use. **Satisfaction** Scale
I am satisfied with the AR system. **Satisfaction** Scale
The AR system was safe and robust. **Effectiveness** Scale
Using the AR system, I felt confident in properly solving the tasks. **Satisfaction** Scale
The AR system was easy to learn. **Learnability** Scale
I did get familiar/used to the AR content quickly. **Learnability** Scale
I had a great overview of the operation and the tasks at hand. **Situation awareness** Scale
Navigating the camera was easy due to the AR information. **Situation awareness** Scale
The AR information provided me with necessary information to complete the tasks. **Satisfaction** Scale
The AR system provided me with too much information. **Satisfaction** Scale
The AR components works well together, creating a comprehensive system. **Satisfaction** Scale
Overall, interacting with the AR components is easy. **Satisfaction** Scale
The AR system worked as I assumed based on the information given before the test. **Satisfaction** Scale

To what degree do you consider the augmented ID board...
... to be helpful? **Effectiveness** Scale
... to be easy to interact with? **Effectiveness** Scale
... to be intuitive? **Effectiveness** Scale
... to be necessary? **Effectiveness** Scale
... to have a suitable font size? **Satisfaction** Scale

... to have suitable colors and contrast? **Satisfaction** Scale
... to have a suitable position? **Satisfaction** Scale
... to have suitable scale? **Satisfaction** Scale

To what degree do you consider the augmented status board...
... to be helpful? **Effectiveness** Scale
... to be easy to interact with? **Effectiveness** Scale
... to be intuitive? **Effectiveness** Scale
... to be necessary? **Effectiveness** Scale
... to have a suitable font size? **Satisfaction** Scale
... to have suitable colors and contrast? **Satisfaction** Scale
... to have a suitable position? **Satisfaction** Scale
... to have suitable scale? **Satisfaction** Scale

To what degree do you consider the augmented "Distance to target" bar...
... to be helpful? **Effectiveness** Scale
... to be easy to interact with? **Effectiveness** Scale
... to be intuitive? **Effectiveness** Scale
... to be necessary? **Effectiveness** Scale
... to have a suitable font size? **Satisfaction** Scale
... to have suitable colors and contrast? **Satisfaction** Scale
... to have a suitable position? **Satisfaction** Scale
... to have suitable scale? **Satisfaction** Scale
... making it easier investigating the holes at a suitable distance? **Effectiveness** Scale

To what degree do you consider the augmented Local map...
... to be helpful? **Effectiveness** Scale
... to be easy to interact with? **Effectiveness** Scale
... to be intuitive? **Effectiveness** Scale
... to be necessary? **Effectiveness** Scale
... to have a suitable font size? **Satisfaction** Scale
... to have suitable colors and contrast? **Satisfaction** Scale
... to have a suitable position? **Satisfaction** Scale
... to have suitable scale? **Satisfaction** Scale
... to provide easier navigation? **Effectiveness** Scale

To what degree do you consider the augmented arrows w/ID...
... to be helpful? **Effectiveness** Scale
... to be easy to interact with? **Effectiveness** Scale
... to be intuitive? **Effectiveness** Scale
... to be necessary? **Effectiveness** Scale
... to have a suitable font size? **Satisfaction** Scale
... to have suitable colors and contrast? **Satisfaction** Scale
... to have a suitable position? **Satisfaction** Scale
... to have suitable scale? **Satisfaction** Scale

... to provide easier navigation? **Effectiveness** Scale

To what degree do you consider the augmented outline of the hole w/size...
... to be helpful? **Effectiveness** Scale
... to be easy to interact with? **Effectiveness** Scale
... to be intuitive? **Effectiveness** Scale
... to be necessary? **Effectiveness** Scale
... to have a suitable font size? **Satisfaction** Scale
... to have suitable colors and contrast? **Satisfaction** Scale
... making it easier visualizing the size and location of the hole? **Effectiveness** Scale

To what degree do you consider the augmented alert...
... to be helpful? **Effectiveness** Scale
... to be easy to interact with? **Effectiveness** Scale
... to be intuitive? **Effectiveness** Scale
... to be necessary? **Effectiveness** Scale
... to have a suitable font size? **Satisfaction** Scale
... to have suitable colors and contrast? **Satisfaction** Scale
... to have a suitable position? **Satisfaction** Scale

Do you have any recommendations making the AR system better? Any type of AR information that may enhance the support? Something you feel missing? Comment
Other comments? Comment

B.2 INTERACTION experiment: Subjective evaluation

Below, the different *questions and statements* of the subjective evaluation are being presented in italic. The **Usability goals** evaluated are written in bold, and the type of question is indicated at the end of the line. Questions related to the evaluation of the systems used in the INTERACTION experiment only, are written in a blue color.

AR system vs traditional system
This section of the evaluation contains statements and questions for evaluating the performance of the AR system compared to the traditional system(with no AR).

The task was easier accomplished using the AR system compared to the traditional system. **Effectiveness** Scale
The tasks were more efficiently solved using the AR system compared to the traditional system. **Effectiveness** Scale
*The holes were easier located and identified with the AR system compared to the traditional system.***Situation awareness** Scale
I felt a greater overview of the operation, and tasks at hand, using the AR system compared to the traditional system. **Situation awareness** Scale
The AR system was more satisfying using than the traditional system. **Satisfaction** Scale

The AR system was more helpful completing the tasks than the traditional system. **Satisfaction** Scale
The AR system increased my productivity compared to the traditional system. **Effectiveness** Scale
The AR system improved the user experience compared to the traditional system. **Satisfaction** Scale
I felt less discomfort and stress using the AR system than the traditional system. **Workload** Scale
The overall workload is smaller using the AR system compared to the traditional system. **Workload** Scale

Did the AR system provide faster learning than the traditional system? **Effectiveness** Multiple-choice question
Did the AR system provide better access to the information than the traditional system? **Effectiveness** Multiple-choice question
Did the AR system provide faster gathering of relevant information than the traditional system? **Effectiveness** Multiple-choice question
Did the AR system provide easier positioning of the stick than the traditional system? **Effectiveness** Multiple-choice question
Do you think that an AR system like this could save time compared to a traditional system without AR? **Effectiveness** Multiple-choice question
Do you think that an AR system like this could improve efficiency compared to a traditional system without AR? **Effectiveness** Multiple-choice question
Do you think that an AR system like this could enhance positioning support compared to a traditional system without AR? **Effectiveness** Multiple-choice question

Other comments? Comment

Detailed evaluation of the AR system

This section contain statements and questions for evaluating the performance, design and usability of the AR system.

The AR information was relevant for solving the tasks. **Satisfaction** Scale
The AR system was easy to use. **Satisfaction** Scale
I am satisfied with the AR system. **Satisfaction** Scale
The AR system was safe and robust. **Effectiveness** Scale
Using the AR system, I felt confident in properly solving the tasks. **Satisfaction** Scale
The AR system was easy to learn. **Learnability** Scale
I did get familiar/used to the AR content quickly. **Learnability** Scale
I had a great overview of the operation and the tasks at hand. **Situation awareness** Scale
Navigating the camera was easy due to the AR information. **Situation awareness** Scale
The AR information provided me with necessary information to complete the tasks. **Satisfaction** Scale
The AR system provided me with too much information. **Satisfaction** Scale
The AR components works well together, creating a comprehensive system. **Satisfaction**

Scale
Overall, interacting with the AR components is easy. **Satisfaction** Scale
The AR system worked as I assumed based on the information given before the test. **Satisfaction** Scale

To what degree do you consider the augmented Depth indicators...
... *to be helpful?* **Effectiveness** Scale
... *to be easy to interact with?* **Effectiveness** Scale
... *to be intuitive?* **Effectiveness** Scale
... *to be necessary?* **Effectiveness** Scale
... *to have a suitable font size?* **Satisfaction** Scale
... *to have suitable colors and contrast?* **Satisfaction** Scale
... *to have a suitable position?* **Satisfaction** Scale
... *to have suitable scale?* **Satisfaction** Scale
... *making the navigation towards the attachment easier?* **Effectiveness** Scale

To what degree do you consider the augmented Direction arrows...
... *to be helpful?* **Effectiveness** Scale
... *to be easy to interact with?* **Effectiveness** Scale
... *to be intuitive?* **Effectiveness** Scale
... *to be necessary?* **Effectiveness** Scale
... *to have suitable colors and contrast?* **Satisfaction** Scale
... *to have a suitable position?* **Satisfaction** Scale
... *to have suitable scale?* **Satisfaction** Scale
... *making the navigation towards the attachment easier?* **Effectiveness** Scale

To what degree do you consider the augmented Target arrow...
... *to be helpful?* **Effectiveness** Scale
... *to be easy to interact with?* **Effectiveness** Scale
... *to be intuitive?* **Effectiveness** Scale
... *to be necessary?* **Effectiveness** Scale
... *to have a suitable font size?* **Satisfaction** Scale
... *to have suitable colors and contrast?* **Satisfaction** Scale
... *to have a suitable position?* **Satisfaction** Scale
... *to have suitable scale?* **Satisfaction** Scale
... *making it easier locating where to attach the stick?* **Effectiveness** Scale

To what degree do you consider the "Hole detected!" alert...
... *to be helpful?* **Effectiveness** Scale
... *to be easy to interact with?* **Effectiveness** Scale
... *to be intuitive?* **Effectiveness** Scale
... *to be necessary?* **Effectiveness** Scale
... *to have a suitable font size?* **Satisfaction** Scale
... *to have suitable colors and contrast?* **Satisfaction** Scale
... *to have a suitable position?* **Satisfaction** Scale

... making the detecting of the hole easier? **Effectiveness** Scale

To what degree do you consider the outline of the hole w/size...
... to be helpful? **Effectiveness** Scale
... to be easy to interact with? **Effectiveness** Scale
... to be intuitive? **Effectiveness** Scale
... to be necessary? **Effectiveness** Scale
... to have a suitable font size? **Satisfaction** Scale
... to have suitable colors and contrast? **Satisfaction** Scale
... making it easier visualizing the size and location of the hole? **Effectiveness** Scale

Do you have any recommendations making the AR system better? Any type of AR information that may enhance the support? Something you feel missing? Comment
Other comments? Comment

Appendix C

Database

Figure C.1 shows the database used in the test procedure of the traditional system in the INFO experiment.

Database

ID	Detected	Size (W x H)	Location	Status	Active/inactive
1	05.03.2019(29 days ago)	3.3 X 7.5	Not critical	Medium urgent	Active
2	01.02.2019(60 days ago)	3.7 X 5.0	Critical	Not urgent	Active
3	02.02.2018(408 days ago)	6.7 X 9.4	Not critical	Not urgent	Inactive
4	02.03.2018(180 days ago)	15.3 X 3.3	Medium critical	Medium urgent	Inactive
5	14.06.2019(122 days ago)	4.4 X 7.7	Medium critical	Medium urgent	Inactive
6	06.09.2018(86 days ago)	9.2 X 9.8	Medium critical	Urgent	Inactive
7	02.03.2019(32 days ago)	5.9 X 7.5	Critical	Urgent	Active
8	02.06.2018(405 days ago)	8.8 X 5.3	Critical	Urgent	Inactive
9	02.03.2019(31 days ago)	2.3 X 6.0	Critical	Urgent	Active
10	14.05.2018(215 days ago)	5.5 X 6.7	Critical	Urgent	Inactive
11	01.01.2019(94 days ago)	7.7 X 3.8	Not critical	Not urgent	Active
12	20.03.2019(14 days ago)	3.3 X 2.7	Medium critical	Not urgent	Active
13	14.02.2019(45 days ago)	5.0 X 8.0	Not critical	Not urgent	Active
14	16.02.2018(305 days ago)	11.5 X 9.0	Critical	Medium urgent	Inactive
15	02.08.2017(565 days ago)	3.3 X 7.3	Critical	Medium urgent	Inactive
16	26.09.2017(522 days ago)	4.4 X 16.4	Medium critical	Medium urgent	Inactive
17	16.02.2019(47 days ago)	9.2 X 2.0	Critical	Not urgent	Active
18	15.01.2019(65 days ago)	5.3 X 9.0	Medium critical	Urgent	Active
19	14.03.2019(18 days ago)	7.3 X 9.5	Medium critical	Medium urgent	Active
20	04.03.2019(30 days ago)	3.3 X 7.9	Not critical	Not urgent	Active
21	21.03.2018(310 days ago)	5.9 X 7.2	Medium critical	Medium urgent	Inactive
22	30.05.2018(290 days ago)	6.2 X 8.8	Medium critical	Not urgent	Inactive
23	08.03.2019(26 days ago)	12.3 X 15.9	Medium critical	Urgent	Active
24	03.02.2019(66 days ago)	2.2 X 2.3	Medium critical	Urgent	Active
25	15.12.2018(94 days ago)	3.3 X 5.0	Critical	Urgent	Inactive
26	02.07.2018(183 days ago)	3.4 X 9.2	Critical	Not urgent	Inactive
27	15.03.2019(19 days ago)	6.4 X 7.9	Not critical	Urgent	Active

Figure C.1: The database used to test the traditional system in the INFO experiment.

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