Evaluation of Design and Suggested Improvements on a Fish Roe Extraction Robot

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Abstract

Modern fish farming requires a great effort by workers in terms of manual and tedious work during the process of hatching fish roe. This work involves removing dead roe by tweezers or siphons, and often times by the use of hazardous chemicals.

This project aims to automate this process to improve efficiency, animal welfare and human working conditions in the aquaculture industry.

To achieve this, it has been proposed to design a robot that performs the extraction of the dead roe. During the work process in this project assignment, several potential ways of improving the current design of the robot have been proposed and evaluated. Most importantly, a new extraction mechanism has been partly built and prepared for further testing in a test rig, and a new way of locating the dead roe by use of stereo cameras has been proposed. This lays an important foundation for future efforts to finalize the robot, and a plan for what needs to be done in a future masters assignment has been presented.

TTK4550

This document details the project assignment performed by Ingebrigt Stamnes Reinsborg for the autumn semester of 2021.

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Chapter 1

Introduction

Aquaculture food production has become an increasingly important source of nutrition for humanity, but also a better source of food in terms of sustainability. In the future, there will be more people, but less resources to produce the things we need if we want to avoid a global climate disaster. Fish and other aquatic sources of food has long been a food staple for communities close to water and the introduction of aquaculture farming has made it possible to produce even more food. However, steps must be made to make this production even more efficient.

A big problem in current fish farming is in the phase where fish roe is shocked with cold water and left in tanks until they hatch. In this phase there will be an estimated 40% of roe that will die and must be removed. Dead roe is a growth medium for a type of freshwater fungus called Saprolegnia, and if the dead roe sits for too long the mycelium will spread and kill nearby healthy roe. It is therefore essential to remove all dead roe continuously until they hatch.

Today, this work is mostly done manually by human workers, often by using a pair of tweezers or by a siphoning tube, sometimes there is also use of chemicals which could be harmful. This work is tedious and monotonous and the aquaculture industry is motivated to automate this process, both for the sake of the workers, but also for lowering the amount of dead roe. If one could get the death rate down from 40% to perhaps 15-20%, this would be a huge leap in production efficiency, animal welfare, sustainability and improvement of workers health.

Since the roe must sit in hatching tanks until they hatch, the best bet for an automated solution would be to design a robot that could identify, locate and extract dead roe unsupervised.

The currently existing robot as of writing this was made by a group of bachelors students, and then further developed by masters students Edda Solem Solem [1] and Marius Tjore Tjore [2], both students at Department of Engineering Cybernetics (ITK). The robot consists of a crossbeam where a rotating rod controlled by a DC stepper motor goes down the middle. In the end of the rotating rod, there is an arm mounted orthogonal on the rotating rod pointing outward. On the arm there is an endpiece that can move up and down driven by a linear actuator. The endpiece can also move across the length of the arm, giving the point of the endpiece mechanism, a range of motion consisting of a cylinder. In technical terms this is called a cylinder robot. Considering the roe is evenly distributed on a circular disk near the surface of the water tank, this is a logical decision.

The plan for how the robot was supposed to extract the roe, included using a small diameter (5mm) plastic tube fastened to the endpiece mechanism connected to a medical pump on the topside level of the robot that would suck the roe out as the endpiece mechanism positioned itself above the roe.

To correctly identify the dead roe, another masters student at NTNU, Marius Tjore, was tasked with finding a computer vision solution by using cameras and a RaspberryPI to do the image processing and identification. The camera was to be placed above the water surface and take pictures of large sections of the roe pool, and then return the positions of the dead roe to the robot for extraction. To find the depth of the eggs, it was proposed to use a laser and Snells law for surface refraction of light.

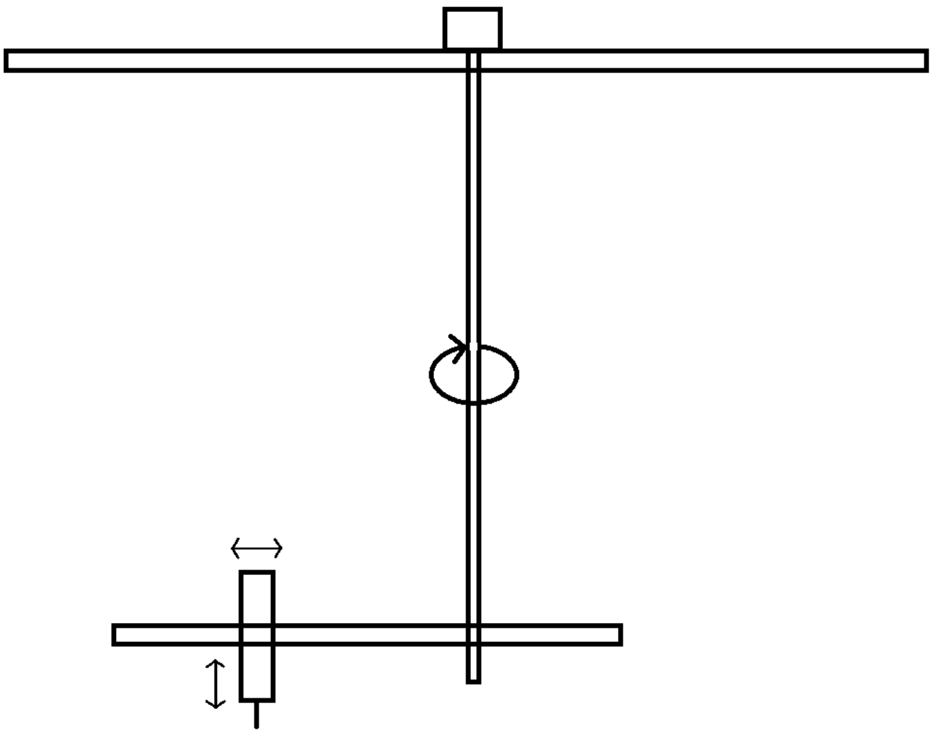

Figure 1.1: Sketch of the Cylinder Robot

Chapter 2

Remaining Challanges

There are quite a few problems with the design of the robot that will have to be solved before this can be a viable solution. To even be able to compete with human workers, some requirements will have to be met; It must be able to operate without supervision for long periods of time, it must be able to extract close to all dead fish eggs, it has to do this with a certain amount of speed and it has to be accurate enough to avoid damaging or accidentally extracting healthy roe. If the dead roe sits for too long, more neighbouring roe will also die. To reformulate, the robot must pick all dead roe quickly and the design must be robust so that the chance of it stopping is minimal.

The robot is going to stand in an industrial hall and operate partly below a water surface. This means it has to handle low temperatures, the circuitry must be resistant to condensation and any part that goes below water should avoid having any movable joints. The argument for the latter is that water will contain biological matter and this might cause damage to any movable joint because of algal growth or wear and tear if joint lubrication is washed away. It will also be easier to maintain if it is just a small part of the robot that needs special consideration for going into the water.

Currently, the robot has some moving parts and some unnecessary volume of stuff on the endpiece that would end up below the water surface and would lead to either corrosion or becoming a growth platform for algae. To improve on this, the new design should strive to end up with something along the lines of a thin straight rod with the extractor tube fastened on the end, that would be lowered to the right position from above the water. Ideally, the tube could be fastened to a plastic rod to keep it in line and a linear actuator lowers it through the surface, so that only the small piece of plastic touches the water. A proposed new type of endpiece mechanism will be discussed later in this assignment.

For the actual extraction, the robot doesn't necessarily have to be faster than a human, since humans typically only work 8 hours per day and a well-functioning robot could work 24/7. It will however, have to be so fast that it can be relocated to several roe tanks over the course of a few days and be able to extract nearly all dead roe. To summarize, a viable robot should at least be as accurate as a human worker, but does not need to be as fast. For now, the accuracy will be a priority and the extraction speed will have to be investigated and optimized according to industry requirements later.

There was some work done in regards of estimating the position and depth of the dead roe in the previous masters assignments, but due to time limitations and challenges related to the COVID-19 pandemic, this work could not be completed. The idea was to use a camera placed around the top part of the robot or above the water surface, looking down on the roe tank, connected to a RaspberryPI running a CV-program made by Marius Tjore Tjore [2] to identify the dead roe and give out the positions, and using a laser and Snells Law to find the depth. This could theoretically work, however, it would not be an efficient solution. The accuracy would also have to be quite high and one would need to do some unnecessarily accurate calibration to achieve this when both camera and laser is placed some distance above the surface. Another problem related to this is that whenever the endpiece mechanism touches the water surface, this will generate waves that will essentially render the laser depth estimation useless until the surface becomes adequately still again. A proposed solution to this is to instead use two cameras in stereo configuration placed below the water surface that would triangulate the positions of the dead roe. This solution will be discussed in the next chapter.

Due to time limitations of the project assignment, the main focus of the work done will be to improve the endpiece mechanism. The following chapter will detail some suggestions for improved solutions, advantages and disadvantages, and the work done to realize the most viable suggestions.

Chapter 3

Materials and Methods

3.1 Endpiece Mechanism

An important factor in making the roe-extraction robot (RER) more viable and precise, is to move the accuracy factor from the topside DC stepper motor down closer to where the extraction happens. To accomplish this there has to be some form of mechanism attached to the rotating arm that can effectively and accurately move the end of the plastic tube to the dead roe. There is also the possibility of roe being buried beneath healthy roe so that the extraction must be done at an angle or from another point of view, so it was therefore envisioned that this proposed mechanism should have some form of spherical movement space.

In this process, three mechanisms were proposed by the author and Glenn Angell of ITKs Mechanical Workshop.

3.1.1 Mechanism 1: Active Ball Joint

The first mechanism to be evaluated is a design based on the ABENICS Active Ball Joint Kazuki abe [3], a spherical gear controlled by monopole gears connected to motors. The active ball joint is constructed as the rotational object one get by rotating a standard gear 180 degress along the X-axis and the Y-axis. Constructing the monopole gears is done by imposing a cylinder with half the circumference and imprint the gear pattern along a half-round on the active ball joint. A 3D-model can be seen in 3.1, this was posted to Thingiverse.com by user Steven Ramirez Ramirez [4]

This mechanism can rotate and move in all angles, meaning it has 3-DOF. The idea was to use this together with a linear actuator mounted through the ball joint which would hold the plastic tube. The active ball joint would move to the correct angle and then the linear actuator would extend to place the tube over the dead roe.

The advantage of this design is that it gives a relatively easy way of controlling the angle of approach for the plastic tube. It is also possible to make an adjusted version of the ball joint where it only has a cog pattern over the field where the

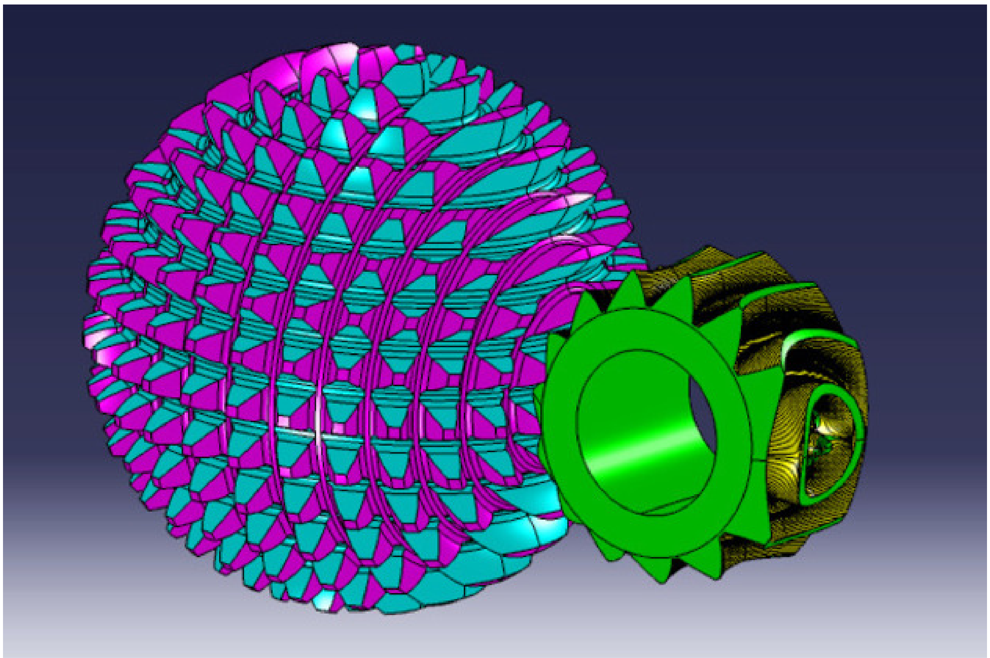

Figure 3.1: ABENICS Active Ball Joint and Monopole Gear

monopole actuator gear is supposed to move corresponding to the opening angle from the ball joint down to the extraction field. This would allow the ball joint to rest in a track with a spherical grove with a hole in the bottom for the linear actuator and extraction tube.

The disadvantage of this mechanism is that the accuracy for the positioning of the extraction tube will not be sufficient for this task. Supposing the dead roe is placed 25cm from the centre of the ball joint (a quick estimate from observing the hatching tank), and you would need an angular accuracy of 0.002 radians (or 0.11 degrees), supposing the extraction tube must have less than a 0.5mm error from the centre of the roe. This level of accuracy will be difficult to achieve since the mechanism has some slack between the teeth of the gears. You could theoretically increase the accuracy by increasing the size of the ball joint, but then it would have to be relatively big and therefore impractical to use.

3.1.2 Mechanism 2: Angular Control by Translation From a 2D-frame

The second mechanism to be considered was proposed by Glenn Angell at ITKs Mechanical Workshop. It can be described as a ball or disc in a track having its rotation controlled by a linear actuator placed some distance above and connected by a rod or band to the ball/disc. The idea of this mechanism is that the movement of the linear actuator will translate to relatively small increments in the angle of the ball/disc, thus achieving the high angular accuracy required for the extraction tube. The degree of freedom for the extraction tube could be expanded from a line to a plane field by adding another linear actuator so that the angle of the ball is determined by the motion of a 2D-frame.

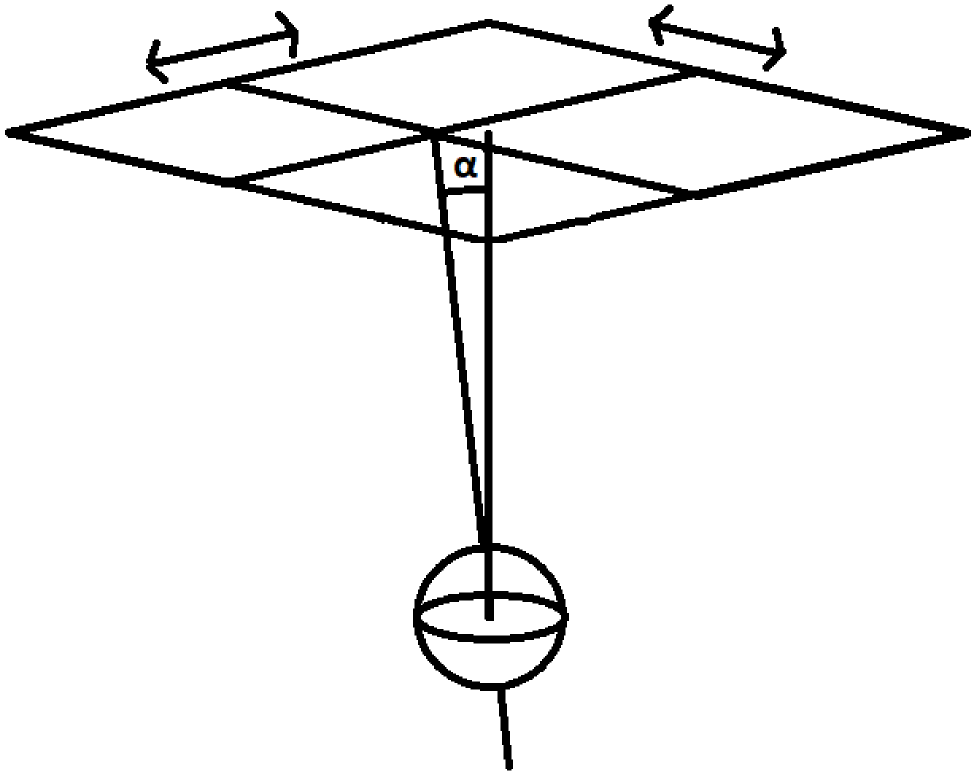

Figure 3.2: The 2D-frame Controlled Ball Mechanism

There's some considerations that must be done regarding the component connecting the 2D-frame and ball; if it's too flexible, it might not be able to move the ball for small movements due to friction from the track, too stiff and it might not be able to move at all. A workaround for this problem could be to use a straight metal rod going from the ball and up into a flexible holder in the 2D-frame that would allow for sliding up and down, and bending to different angles, a universal joint with gliding.

The main advantages of this mechanism is that it's relatively easy to make, very accurate, and gives high flexibility in terms of future adjustments. The kinematics would also be relatively simple as the direction of the extraction tube could easily be computed as the line defined as the one going between the universal joint in the 2D-frame and the centre of the ball, and then simply compute the correct distance for the extraction tube to extend.

However, the structure would be rather bulky and more difficult for the cylinder robot to maneuver. It would also require a higher amount of parts moving in tracks with a high requirement of low friction (the metal rod in the universal joint and the ball), which would be sensitive to corrosion, wear and tear.

3.1.3 Mechanism 3: Stewart Platform-Inspired Tripod

The final idea was to use a mechanism similar to a Stewart platform. A Stewart platform Stewart [5] is a parallel manipulator with typically six linear actuators connected between a base and a platform, normally from three pairwise positions from the base going to two pairwise positions on the platform (3-3 type), but can also go from six singular points on the base to three pairwise points on the platform (6-3 type) or other types of configuration. By varying the lengths of the linear actuators, different angles and translations can be produced by the platform. A Stewart platform provides 6-DOF (X-Y-Z and roll-pitch-yaw). For our case, it is not necessary with 6-DOF, only pitch, roll and extractor length need to be controlled in order to reach the roe. Reducing the amount of linear actuators to three, spaced 120 degrees apart will provide these 3-DOF that are needed. However, although they provide control over height (extension and retraction of all actuators), it will be better to also have a fourth linear actuator going through the centre of the roll-pitch-controlled platform to be aimed towards the dead roe, allowing it to extend and extract. This allows the three platform-connected actuators to be solely focused on correct roll and pitch, and the fourth for radial length. This technically gives the mechanism a 4-DOF functionality, but for simplification one could design a control algorithm such that the height given by the three platform-connected actuators never diverge.

By adjusting the size of the base compared to the controlled platform, it is possible to adjust the level of angular change per change in length for the linear actuators. If the base is smaller than the platform, any movement by the linear actuators will give small angle changes. If the base is bigger, the angle of the platform will change more per movement of the linear actuators. Since this task requires high accuracy, it is appropriate to set the size of the base smaller than the platform.

There are several advantages to this mechanism. First of all, the actuators are all the same and will use the same form of input, making the process of control easier. The structure is quite stable and accurate compared to the two other mechanisms. It would require less space than the "2D-frame connected to ball"-mechanism, and it would have less mechanical slack than the active ball joint. It is also possible that this mechanism is more resistant to wear and tear since the only movable parts are the linear actuators.

Disadvantages to this mechanism could be that the movements between roe could be slower than for the two other mechanisms. This is however, very hard to determine without actually realizing each solution and do a check.

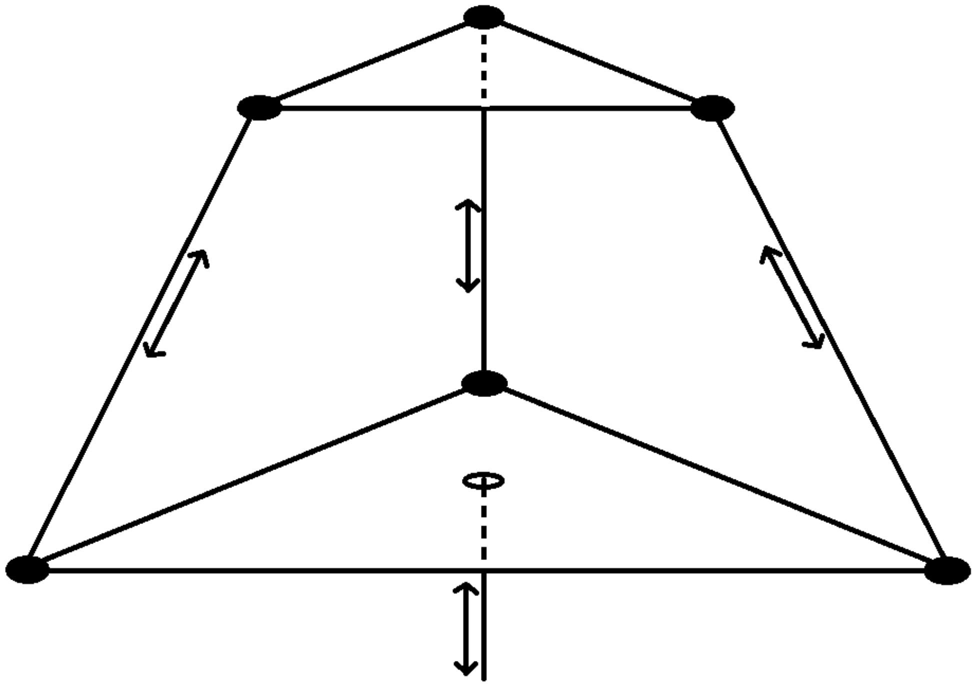

Figure 3.3: The Stewart Platform-Inspired Mechanism

3.1.4 Deciding what to use

In the end, it was decided that the Stewart platform-like mechanism would be the most suitable for this task. It avoids the problems related to having moving objects in low-friction tracks, offers a simple way of gaining high angular accuracy, and is easy to build and repair.

However, it needs to be stated that all these proposed mechanisms could have worked, and that there might be other solutions that are far better suited. This chapter only serves to explain the motivation behind the choice to use a Stewart Platform-like mechanism, and to discuss potential advantages and disadvantages with some suggested solutions. Either way, it is a good starting point in terms of solving the current problems with the RER.

3.2 Construction and Components

After deciding what type of mechanism to use, the construction could start. The linear actuators used in this project are of the type Actuonix L16-P Inc [6], which have a stroke length of 100mm, variable speed and several different ways of giving input for control. Combined with a Linear Actuator Control-board (LAC-board), it provides an easy environment and framework for writing control algorithms.

The base and platform plates were cut from steel plates in roughly equilateral triangular shapes. The platform was made to be approximately three times the size of the base and given several sets of mounting holes for the universal joints connecting to the linear actuators, which will allow for further testing to determine the most fitting size ratio between the base and platform. The SP was built by ITKs Mechanical Workshop.

To be able to run tests on the Stewart Platform (SP), a test rig had to be constructed. The rig simply holds the SP some height above the table to allow for freedom of movement and holds the necessary equipment needed to run the motors. To deliver power to the linear actuators, a simple power delivery system was made with some cabling, a perfboard and a 12V supplied by a power supply. To provide control input, an Arduino UNO was used. This test rig will simplify the process of prototyping compared to just mounting it directly on the RER, since structural adjustments can be done far easier and new control code can be flashed through an easily accessible USB cable. Once the most optimal heights and ratios have been determined, the SP can be mounted on the RER. The rig can also be adapted to include holders for the cameras to perform necessary tests to determine the most suitable positions and angles to achieve a stereo-CV system that reliably finds all dead roe within the robots reachable volume.

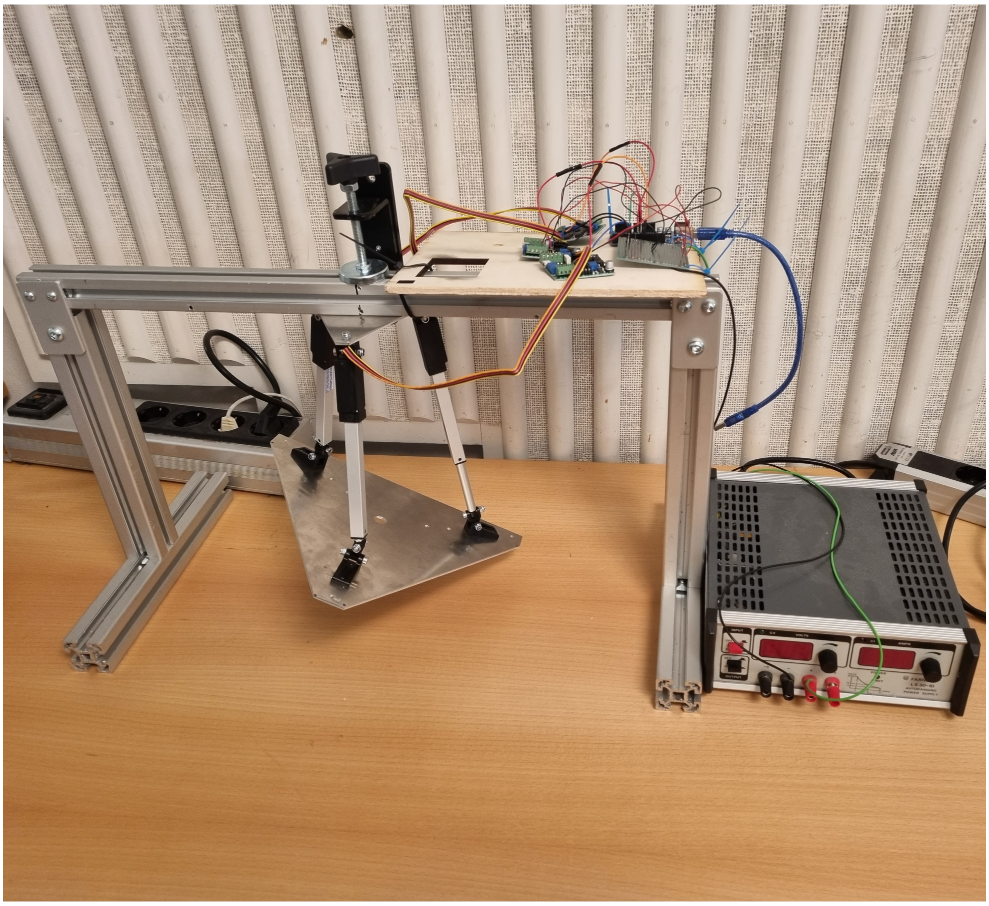

Figure 3.4: The Finished Test Rig

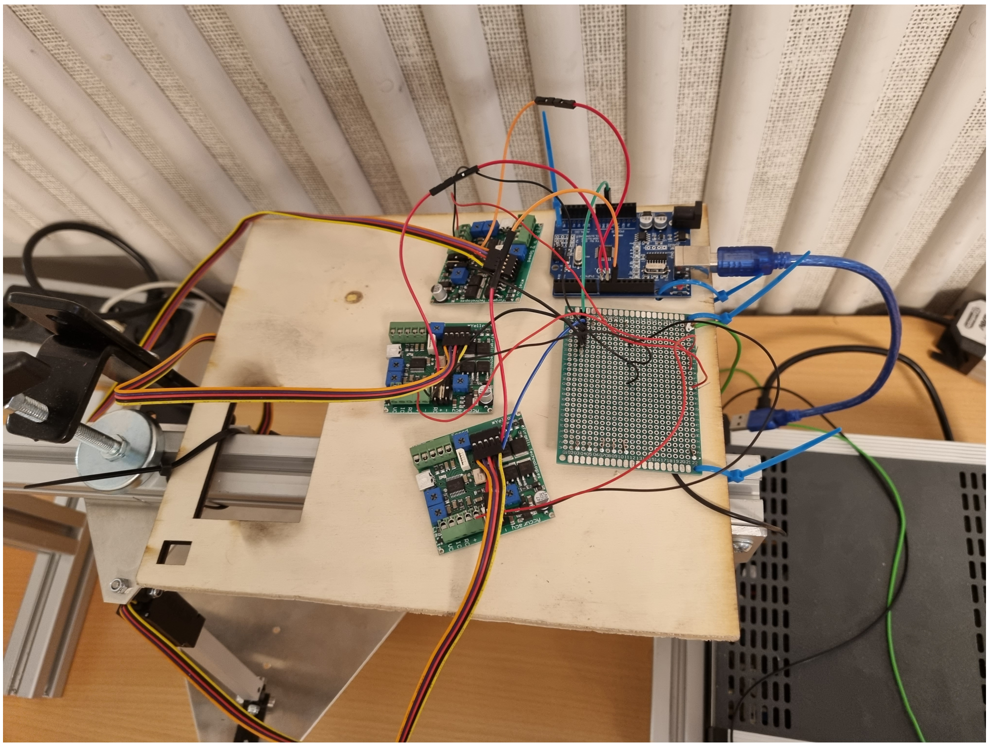

Figure 3.5: Picture of Electronic Components of the Test Rig

Radius base	5cm
Radii platform	5cm, 7.5cm, 10cm, 12.5cm
Height between base and platform (non-extended)	20cm

By doing some simplifications, it is possible to estimate the angular change for the smallest movement by the linear actuator per set radius of the platform. Intuitively, it can be imagined that one linear actuator produces a rotation around an axis defined by the line between the universal joints of the two other actuators. The orthogonal line from the moved actuator to the imagined axis will serve as a radius in this calculation, these four orthogonal lines lengths are given by the four radii of the different mounting holes of the platform multiplied by 1.5. Calculating these lengths gives us: 7.5cm, 11.25cm, 15cm and 18.75cm. According to Inc [6] the Actuonix L16-100-P has a repeatability of 0.4mm, assuming this to be the smallest reliable movement it can make, the corresponding angular change will be as follows:

Platform Radius	Smallest Angular Movement
5cm	0.0053 radians
7.5cm	0.0036 radians
10cm	0.0027 radians
12.5cm	0.0021 radians

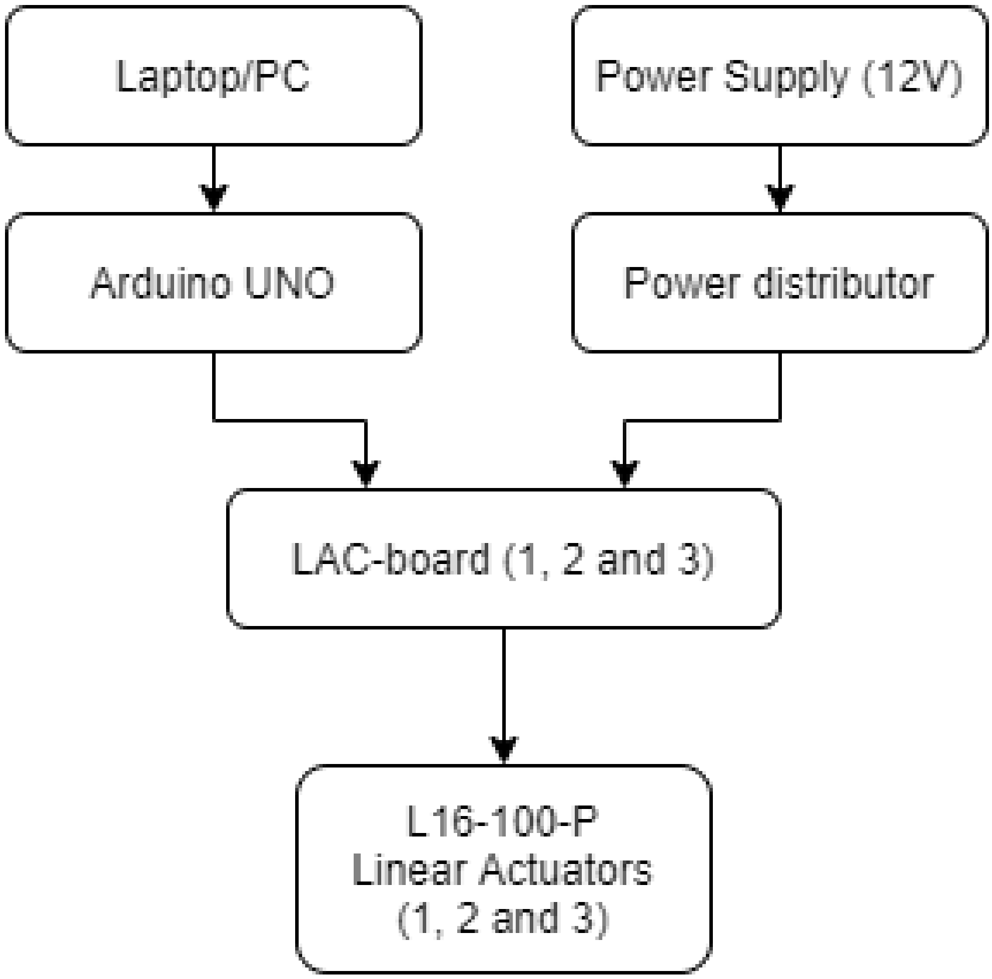

Figure 3.6: Flowchart of Test Rig Components

Assuming it is needed an accuracy of 0.5mm to extract the intended roe, and that the roe is located 15cm from the centre of the platform, the corresponding angular accuracy needed will be around 0.003 radians. From this we can already now assume that choosing a platform radius of 10cm will be sufficient. However, this will have to be tested once more accurate structural parameters are decided.

3.3 Kinematics

Before any type of control-algorithm can be constructed, an overview of the kinematics must be obtained. As stated earlier, the mechanism consists of a smaller upper base where three linear actuators are connected by universal joints between a base and a platform 120 degrees apart.

Luckily a similar robot has been considered for use in pipeline restoration and has been explained thoroughly in the masters thesis of Derek K. Brecht at The University of Western Ontario Brecht [7]. Here a detailed overview of the kinematics of this type of mechanism has been provided, which can be adapted to be used in this project.

The universal joints of the base and platform can be represented in coordinate systems centered around each plane:

Upper base:

$$^{B}b_1 = [r, 0, 0]^T \tag{3.1a}$$

$$^{B}b_2 = [-\frac{1}{2}r, \sqrt{\frac{3}{2}}r, 0]^T \tag{3.1b}$$

$$^{B}b_3 = [-\frac{1}{2}r, -\sqrt{\frac{3}{2}}r, 0]^T \tag{3.1c}$$

Platform:

$$^{P}p_1 = [R, 0, 0]^T \tag{3.2a}$$

$$^{P}p_2 = [-\frac{1}{2}R, \sqrt{\frac{3}{2}}R, 0]^T \tag{3.2b}$$

$$^{P}p_3 = [-\frac{1}{2}R, -\sqrt{\frac{3}{2}}R, 0]^T \tag{3.2c}$$

Where r and R are the radii of the base and platform respectively.
Since rotation around the z-axis or yaw is not considered as an ability of this system, we can consider just pitch and roll (rotation around x- and y-axis). Intuitively, it is possible to see that no configuration of the linear actuators will facilitate a rotation around the z-axis.

In the masters thesis, it is provided a rotation matrix $^{P}R_B$ that is to be used in a transformation matrix $^{B}T_B$ that relates from the base reference frame to platform reference frame

$$^{P}R_B = \begin{bmatrix} \cos\theta\cos\phi & \cos\theta\sin\phi & -\sin\theta \\ \sin\psi\sin\theta\cos\phi - \cos\psi\sin\phi & \sin\psi\sin\theta\sin\phi - \cos\psi\cos\phi & \cos\theta\sin\psi \\ \cos\psi\sin\theta\cos\phi - \sin\psi\sin\phi & \cos\psi\sin\theta\sin\phi - \sin\psi\cos\phi & \cos\theta\cos\psi \end{bmatrix} \tag{3.3}$$

$$^{B}T_{B} = \begin{bmatrix} ^{P}R_{B} & q \\ 0 & 1 \end{bmatrix} \tag{3.4}$$

The q-vector here is the vector from origin in base frame to origin in platform frame. If the linear actuators are extended to equal lengths, then this vector only has a negative value corresponding to height since the origins are directly on top of each other. While in different configurations, this vector will have non-zero values for X and Y as well.

By using:

$$^{P}\begin{bmatrix} P_i x \\ P_i y \\ P_i z \\ 1 \end{bmatrix} =^{B} T_{B}^{P} * \begin{bmatrix} p_i x \\ p_i y \\ p_i z \\ 1 \end{bmatrix} \tag{3.5}$$

One can translate from the platform reference frame to the base platform frame. By using the difference between the corresponding coordinates of the universal joints, one can calculate the euclidean distance between them, giving us the lengths of each motor.

$$l_1 = \sqrt{(P_{1x} - b_{1x})^2 + (P_{1y} - b_{1y})^2 + (P_{1z} - b_{1z})^2} \tag{3.6a}$$

$$l_1 = \sqrt{(P_{2x} - b_{2x})^2 + (P_{2y} - b_{2y})^2 + (P_{2z} - b_{2z})^2} \tag{3.6b}$$

$$l_1 = \sqrt{(P_{3x} - b_{3x})^2 + (P_{3y} - b_{3y})^2 + (P_{3z} - b_{3z})^2} \tag{3.6c}$$

This should according to D. K. Brecht be enough to determine the required length of each actuator as long as we are provided with the desired angles and position of the platform origin in base reference frame.

All this is taken from the masters thesis of Derek K. Brecht and will provide a useful kinematic framework for a future control algorithm, which will be a topic in a later masters thesis.

An attempt at making a python script doing these calculations using NumPy-Harris *et al.* [8] has been performed and can be found in appendix B. By double checking the resulting rotation matrices from inputting simple rotations around one axis at the time, it was found that they were the same as those listed in Olav Egeland [9] page 222. This was simply done to confirm that the matrix had been entered correctly.

3.4 Finding the position of dead roe

As mentioned earlier, the original idea of using a single camera and a laser depth measurement to retrieve roe positions is most likely a difficult method. A better and far simpler solution would be to use two cameras in stereo, placed below the water surface each connected to a computer running the CV-program. This increases accuracy by placing the cameras closer to the roe, you would avoid having to use the laser depth estimation technique and disturbances in the surface become irrelevant. It would also be possible to use less expensive cameras, e.g. the Raspberry Pi cameras, since the demand for resolution and image quality is lessened as the distance between camera and roe is much smaller.

Stereo vision works by having two or more cameras placed at a known spatial location which then take a picture of the same object. Since the position and orientation of the cameras are known, it is possible to compare where the photographed object is in each picture and from this triangulate the objects position.

A stereo vision system using OpenCV and RaspberryPi has been documented in Pomaska [10]. Here, code examples in Python for a stereo vision system is provided to the reader, in addition there are instructions for how to calibrate the cameras and also some information about infrared photography.

Chapter 4

Discussion

In this project assignment several potential problems and solutions have been mentioned and discussed, resulting in the decision to start the development of a Stewart platform-inspired extraction mechanism and a stereo computer vision-solution for finding position of dead roe. The constructed test rig provides an easily accessible module for testing code, control algorithms and adjusting physical parameters such as height, platform radius and camera placement. This will streamline the future efforts of finding the optimal spacial configuration, which will then be used when the new cylinder robot is assembled with the new extraction mechanism.

To achieve a working stereo vision solution as proposed, there will have to be an investigation regarding what angle towards the "roe-field-plane" the cameras can placed at. Ideally, placing them at a low angle will let them cover a wider field, but cameras have limitations regarding simultaneous focus on near and far objects, meaning that roe near and far away might become too unclear for a CV-program to identify. It might also be necessary to use three cameras, to achieve an accurate enough positioning of the dead roe. These limits and challenges will have to investigated as a part of the future work.

When both extraction mechanism and stereo vision are in working order, the cylinder robot should be reassembled and prepared for testing in a test environment as close as possible to a real life situation. There must be an electronic infrastructure that alerts the cylinder robot [1] that the extraction mechanism has picked its current working area free of dead roe, so that it can be moved to the next area. There might also be other functionalities that are required, e.g. automatic calibrations, alerts in case it ceases to function, or a way to alert personnel that the tank is picked free. How much of this can be implemented will depend on however much time is left after testing and reassembly. The most vital thing to achieve is that it actually is able to pick dead roe.

[1] or perhaps disc robot since up-down-movement is a part of the new extraction mechanism

Chapter 5

Conclusion

In this project, the goal was to find improvements for a robot that is supposed to extract dead roe from hatching tanks and if possible implement these. Several potential improvements were found and discussed, and the groundwork for future implementation of some of these improvements have been made. A plan regarding necessary tests and areas of further research has been provided and will serve as a work plan for a future masters assignment.

Bibliography

[1] E. Solem, 'Robot for kvalitetsortering av øyerogn av laksefisk,' 2020.

[2] M. Tjore, 'Machine vision for quality sorting of salmonid fish eggs,' 2020.

[3] R. T. Kazuki abe Kenjiro Tadakuma, 'Abenics: Active ball joint mechanism with three-dof based on spherical gear meshings,' *IEEE TRANSACTIONS ON ROBOTICS*, 2021.

[4] S. Ramirez, 'Gears for abenics active gear joint,' *Thingiverse.com*, vol. https://www.thingiverse.com/thing:4891402, 2021.

[5] D. Stewart, 'A platform with six degrees of freedom,' vol. 180, 1965.

[6] A. M. D. Inc, 'Miniature linear motion series,' 2018.

[7] D. K. Brecht, 'A 3-dof stewart platform for trenchless pipeline rehabilitation,' *Electronic Thesis and Dissertation Repository. 3156.*, 2015.

[8] C. R. Harris, K. J. Millman, S. J. van der Walt, R. Gommers, P. Virtanen, D. Cournapeau, E. Wieser, J. Taylor, S. Berg, N. J. Smith, R. Kern, M. Picus, S. Hoyer, M. H. van Kerkwijk, M. Brett, A. Haldane, J. F. del Río, M. Wiebe, P. Peterson, P. Gérard-Marchant, K. Sheppard, T. Reddy, W. Weckesser, H. Abbasi, C. Gohlke and T. E. Oliphant, 'Array programming with NumPy,' *Nature*, vol. 585, no. 7825, pp. 357–362, Sep. 2020. DOI: `10.1038/s41586-020-2649-2`. [Online]. Available: `https://doi.org/10.1038/s41586-020-2649-2`.

[9] J. T. G. Olav Egeland, 'Modeling and simulation for automatic control,' pp. 209–262, 2003.

[10] G. Pomaska, 'Stereo vision applying opencv and raspberry pi,' *Remote Sensing and Spatial Information Sciences*, vol. Volume XLII-2/W17, 2019, 2019.

Appendix A

Additional Material

NTNU
Norges teknisk-naturvitenskapelige universitet

Fakultet for informasjonsteknologi og elektroteknikk
Institutt for teknisk kybernetikk

PROSJEKTOPPGAVE

Kandidatens navn: Ingebrigt Reinsborg Stamnes

Fag: Teknisk Kybernetikk

Oppgavens tittel (norsk): Eggrobot: robot for deteksjon og utplukking av døde røyeegg

Oppgavens tittel (engelsk): Egg robot: robot for detection and removal of dead char eggs

Oppgavens tekst:
Sopp er et problem på øyerogn av laksefisk og sprer seg raskt mellom rognkorn dersom de infiserte ikke blir fjernet raskt nok. Det skal utvikles en robot som benytter maskinsyn for klassifisering av infiserte og/eller døde rognkorn. Robotarmen vil være utstyrt med et kamera og en utsugingsenhet. Denne monteres over klekkebakken, og robotarmen flytter seg rundt til hele arealet er scannet. Rognkorn av dårlig kvalitet identifiseres, posisjonsbetemmes og suges ut av roboten.

En tidlig prototype av robotarmen og maskinsynsystemet har tidligere blitt utviklet. Designet har imidlertid noen potensielle svakheter, og integrasjon av robotarm og programvare for maskinsyn er ikke gjennomført. I denne oppgaven skal hardwaredesignet vurderes og eventuelt forbedres, og en integrert versjon med styringssystem og maskinsynsystem demonstreres.

Oppgaven oppsummeres i følgende punkter:

- Basert på tidligere masteroppgaver og den eksisterende prototypen, vurder hvilke utbedringer som må gjøres i hardwaredesignet.
- Kartlegging og vurdering av alternative design. Implementasjon av nytt design og utforming av test- og kalibreringsprosedyrer.
- Anbefalinger for videre utvikling av systemet.

Oppgaven gitt: 23. august 2021
Besvarelsen leveres innen: 20. desember 2021

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Trondheim, 23. august 2021

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Faglærer

Appendix B

Python Script for Kinematic Calculations

```
# -*- coding: utf-8 -*-
"""
Created on Mon Dec 13 14:51:16 2021

@author: ingebrsr
"""

import numpy as np
import matplotlib as plot

r     = 5 #These must be measured properly
R     = 15
psi   = 0 # X, Roll
theta = 0 # Y, pitch
phi   = 0 # Z, Yaw.    i paperet, z-rotasjon, skal være 0

p_1 = np.array([r, 0, 0])
p_2 = np.array([-0.5*r, np.sqrt(1.5)*r, 0])
p_3 = np.array([-0.5*r, -np.sqrt(1.5)*r, 0])

p = np.array([p_1, p_2, p_3, [1, 1, 1]])

b_1 = np.array([R, 0, 0])
b_2 = np.array([-0.5*R, np.sqrt(1.5)*R, 0])
b_3 = np.array([-0.5*R, -np.sqrt(1.5)*R, 0])

b = np.array([b_1, b_2, b_3, [1, 1, 1]])

q = np.array([0, 0, 0])

R_p_1 = np.array([np.cos(theta)*np.cos(phi), np.cos(theta)*np.sin(phi), -np.sin(theta)])

R_p_2 = np.array([(np.sin(psi)*np.sin(theta)*np.cos(phi) - np.cos(psi)*np.sin(phi)),
                (np.sin(psi)*np.sin(theta)*np.sin(phi) + np.cos(psi)*np.cos(phi)),
                np.cos(theta)*np.sin(psi)])

R_p_3 = np.array([(np.cos(psi)*np.sin(theta)*np.cos(phi) + np.sin(psi)*np.sin(phi)),
                (np.cos(psi)*np.sin(theta)*np.sin(phi) - np.sin(psi)*np.cos(phi)),
                np.cos(theta)*np.cos(psi)])
```

```
T_p_1 = np.array([np.cos(theta)*np.cos(phi), np.cos(theta)*np.sin(phi), -np.sin(theta), q[0]])

T_p_2 = np.array([(np.sin(psi)*np.sin(theta)*np.cos(phi) - np.cos(psi)*np.sin(phi)),
                (np.sin(psi)*np.sin(theta)*np.sin(phi) + np.cos(psi)*np.cos(phi)),
                np.cos(theta)*np.sin(psi), q[1]])

T_p_3 = np.array([(np.cos(psi)*np.sin(theta)*np.cos(phi) + np.sin(psi)*np.sin(phi)),
                (np.cos(psi)*np.sin(theta)*np.sin(phi) - np.sin(psi)*np.cos(phi)),
                np.cos(theta)*np.cos(psi), q[2]])

T_p_4 = np.array([0, 0, 0, 1])

R_p = np.array([R_p_1, R_p_2, R_p_3])

T_p = np.array([T_p_1, T_p_2, T_p_3, T_p_4])

P = T_p @ p

l_1 = np.sqrt(((P[0][0] - b[0][0])**2) + ((P[0][1] - b[0][1])**2) + ((P[0][2] - b[0][2])**2))
l_2 = np.sqrt(((P[1][0] - b[1][0])**2) + ((P[1][1] - b[1][1])**2) + ((P[1][2] - b[1][2])**2))
l_3 = np.sqrt(((P[2][0] - b[2][0])**2) + ((P[2][1] - b[2][1])**2) + ((P[2][2] - b[2][2])**2))

l = np.array([l_1, l_2, l_3])

print(R_p)
print(T_p)
print(P)
print(l)

print("Run complete")
```