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# Grayscale & Colored Camera Feeds for Mobile Augmented Reality Navigation

Master's thesis in Interaction Design

Supervisor: Ole E. Wattne

June 2020

NTNU  
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# Abstract

Mobile augmented reality applications are comprised of three components: the camera feeds, the virtual objects rendered on top of such camera feeds (e.g. virtual navigation signage), and the application interface (e.g. icons, menus). While the last two components have been relatively explored, very few literatures studied the first component – the camera feeds, especially in terms of color design.

This study evaluates if rendering the camera feeds in Grayscale mode, instead of Colored mode, is effective for mobile augmented reality navigation. By having the camera feeds in Grayscale mode, the user's visual attention is hypothesised to be towards the important elements of a mobile augmented reality navigation application - the virtual navigation signage. In addition, this study also examines the user's satisfaction in using the Grayscale mode as compared to the Colored mode.

An experiment was conducted with two simple indoor navigation tasks performed by the research participants, one in Grayscale mode and the other in Colored mode. Effectiveness (Time Taken) and User Satisfaction (Easiness, Enjoyability) were measured. Due to the COVID-19 situation, the experiment was conducted online with research participants performing the navigation tasks on a computer. Such an approach was a deviation from the originally planned experiment which was to be conducted in person using mobile augmented reality.

The results from the study statistically suggested no significant differences between Grayscale mode and Colored mode navigation.

**Keywords:** camera feeds, grayscale, color, mobile augmented reality, navigation, effectiveness, user satisfaction.

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# Contents

<b>Abstract</b>	<b>ii</b>
<b>Table of Contents</b>	<b>iii</b>
<b>List of Tables</b>	<b>vi</b>
<b>List of Figures</b>	<b>vii</b>
<b>Abbreviations</b>	<b>1</b>
<b>1 Introduction</b>	<b>2</b>
1.1 Research Problem . . . . .	2
1.2 Research Justifications & Motivations . . . . .	2
1.3 Research Questions . . . . .	3
1.4 Research Significance & Planned Contributions . . . . .	3
1.5 Research Delimitation . . . . .	4
1.6 Research Assumption . . . . .	4
<b>2 Theoretical Background, Literature Review &amp; Research Hypotheses</b>	<b>5</b>
2.1 Augmented Reality & Mobile Augmented Reality . . . . .	6
2.1.1 Augmented Reality . . . . .	6
2.1.2 Mobile Augmented Reality (MAR) . . . . .	7
2.1.3 AR/MAR Tracking Systems . . . . .	8
2.2 Spatial Knowledge & Navigation Aids . . . . .	8
2.3 Color in Augmented Reality . . . . .	9
2.4 Selective Visual Attention and Color Information . . . . .	11
2.4.1 Selective Visual Attention . . . . .	11
2.4.2 Color Information Effects on Selective Visual Attention . . . . .	12
2.5 Virtual Environments & Gender Differences . . . . .	13

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2.6	Research Hypotheses and Research Variables . . . . .	15
2.6.1	Hypothesis 1 - Effectiveness . . . . .	15
2.6.2	Hypothesis 2 - User Satisfaction . . . . .	15
<b>3</b>	<b>Methods</b>	<b>16</b>
3.1	Choices of Methods . . . . .	16
3.1.1	Quantitative Study . . . . .	16
3.1.2	Qualitative Study . . . . .	18
3.2	Research Participants . . . . .	18
<b>4</b>	<b>Research Experiment</b>	<b>19</b>
4.1	Originally Planned versus Actually Conducted Experiment . . . . .	19
4.2	Test Participants Recruitment . . . . .	21
4.3	Experiment Tasks . . . . .	21
4.4	Experiment Procedure . . . . .	22
4.4.1	Experiment Overview . . . . .	22
4.4.2	Data Collection and Confidentiality . . . . .	23
4.4.3	Demo Tutorial Task . . . . .	23
4.4.4	Navigation Task 1 & Post-task Questionnaire . . . . .	25
4.4.5	Navigation Task 2 & Post-task Questionnaire . . . . .	26
4.4.6	Post-study Questionnaire . . . . .	26
4.5	Survey Questionnaires . . . . .	27
4.6	Experiment Testing Environment . . . . .	29
4.6.1	Scene Setup . . . . .	30
4.6.2	First-person View . . . . .	33
4.6.3	Directional Signage . . . . .	34
4.6.4	Target Destination . . . . .	37
4.6.5	C# Scripts . . . . .	38
4.7	Experiment Design Considerations . . . . .	39
4.7.1	Colored vs Grayscale Scene . . . . .	39
4.7.2	Counterbalancing with Two Google Form Sets . . . . .	39
4.7.3	Use of Demo Tutorial . . . . .	40
<b>5</b>	<b>Results</b>	<b>41</b>
5.1	Demographics . . . . .	41
5.2	Quantitative Analysis . . . . .	41

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5.2.1	Time Taken . . . . .	41
5.2.2	Easiness . . . . .	43
5.2.3	Enjoyability . . . . .	44
5.2.4	Overall Preference by Gender . . . . .	45
5.3	Qualitative Analysis . . . . .	47
5.3.1	Words Cloud . . . . .	48
5.3.2	Themes from Comments . . . . .	48
<b>6</b>	<b>Discussion</b>	<b>51</b>
6.1	Possible Reasons for the Indifference . . . . .	51
6.1.1	Field of View and Exploration Level . . . . .	51
6.1.2	Depth of View and Color Advantages . . . . .	52
6.1.3	Task Complexity . . . . .	53
6.2	Alternative View - No Difference . . . . .	53
6.3	Restricted Qualitative Data . . . . .	54
6.4	Research Limitation . . . . .	54
<b>7</b>	<b>Conclusion</b>	<b>57</b>
<b>8</b>	<b>Personal Learning Outcome</b>	<b>58</b>
	<b>Bibliography</b>	<b>59</b>
	<b>Appendix</b>	<b>63</b>
A	Google Survey Form . . . . .	64
B	Letter of Information and Consent Form . . . . .	69
C	Experiment Footage Video & 3D Models Sources . . . . .	71
D	Qualitative Analysis - Comment Themes . . . . .	72

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# List of Tables

T4.1	Originally Planned vs Actually Conducted Experiment . . . . .	21
T4.2	Counterbalancing - Task execution order . . . . .	40
T5.1	Time Taken by Gender - Independent samples t-Test . . . . .	43
T5.2	Easiness - Wilcoxon signed tanks test . . . . .	44
T5.3	Enjoyability - Wilcoxon signed ranks test . . . . .	45
T5.4	Overall Preference by Gender - M. Whitney U-test . . . . .	47
T5.5	Comment themes & Number of comments received . . . . .	50
T8.1	3D Models Sources . . . . .	71

# List of Figures

F2.1	Milgram’s “virtuality continuum” . . . . .	6
F4.1	Originally Planned experiment vs Actual experiment . . . . .	20
F4.2	Experiment survey form - Welcome screen . . . . .	23
F4.3	Demo tutorial - Welcome screen with guides . . . . .	24
F4.4	Demo tutorial - Environment screenshot . . . . .	24
F4.5	Navigation task - Instructions and URL . . . . .	25
F4.6	Navigation task - Time taken recorded . . . . .	26
F4.7	Post-task questionnaire - Sample questions . . . . .	28
F4.8	Post-study questionnaire - Overall preference rating question . . . . .	29
F4.9	Scene design - Office furniture setup . . . . .	30
F4.10	Scene design - Unity top view with grid displayed . . . . .	31
F4.11	Scene design - Signage along the wall . . . . .	31
F4.12	Scene design - Unity color grading settings . . . . .	32
F4.13	Scene design - Unity first-person camera view . . . . .	33
F4.14	Scene design - Signage in Colored environment . . . . .	34
F4.15	Scene design - Signage in Grayscale environment . . . . .	35
F4.16	Scene design - Signage appearance settings . . . . .	36
F4.17	Scene design - Penguin as target destination . . . . .	37
F4.18	Scene design - Penguin with collision area . . . . .	38
F5.1	Overall Preference by Gender - Frequency in Percentage . . . . .	46
F5.2	Qualitative analysis - Words cloud generated . . . . .	48

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# Abbreviations

2D	=	2-Dimensional
3D	=	3-Dimensional
AR	=	Augmented Reality
CVD	=	Color Vision Deficiency
MAR	=	Mobile Augmented Reality
URL	=	Uniform Resource Locator
VE	=	Virtual Environment
VR	=	Virtual Reality

# Introduction

## 1.1 Research Problem

Being able to capture visual attention to important design elements is a desirable feature of good designs. Color is one of the ways to achieve that. In many cases, the Grayscale background is rendered in contrast with colored visual elements to highlight the elements and capture attention. Grayscale could also be used in different situations where there is a need to reduce the information overload caused by colors.

In the context of Mobile Augmented Reality (MAR) navigation experience, this study explores a different way to display camera feeds, which is one of the three components of MAR (besides the virtual objects rendered and the application interface such as menus, and icons). Specifically, this study evaluates if rendering the camera feeds in Grayscale mode (as opposed to Colored mode) would improve the navigation experience using MAR.

## 1.2 Research Justifications & Motivations

The idea of rendering the camera feeds in Grayscale mode is to increase the visual salience of the virtual navigation aids (e.g. arrows) rendered on top of the same camera feeds. In that way, the users' visual attention is captured on important elements required for the task at hand, i.e. the directional signage.

Limited studies have been done and not many guidelines have been established for

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designing MAR navigation applications even though MAR has increasingly been used in various domains including wayfinding and navigation.

The current literature about designing for MAR and MAR Navigation mainly focuses on two MAR components: the virtual objects and the application interface with menus, icons, and instructional texts. Few studies have considered the third component of MAR – the real-world component, i.e. the camera feeds. The literature available for the third component is even less for color design. With that in mind, this study explores this third component, the camera feeds, in terms of color mode rendering.

### **1.3 Research Questions**

The research questions for this study include:

1. What are the visual elements of MAR?
2. How color information affect visual attention? Do Colored images/videos yield different effects on visual attention, as compared to Grayscale images/videos?
3. What are the guidelines available in the literature about color in augmented reality and mobile augmented reality?
4. Is there any gender difference in relating to navigation using MAR, particularly in the context of color rendering?

These research questions would be examined in Chapter 2 Theoretical Background, Literature Review & Research Hypotheses. The research hypothesis would then be formed.

### **1.4 Research Significance & Planned Contributions**

The planned contributions of this research include:

- The study suggests design considerations for the camera feed, an important component of MAR that has not been well studied in current literature.
- The study result could be further developed into design guidelines for navigation with AR and MAR.

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- If Grayscale mode is proved to be effective for MAR navigation, this research could set a starting ground for other future researches in two aspects:
    - Replacing colored mode with the Grayscale mode in MAR applications where possible since color-to-grayscale conversion could mean less data required for transmission. Compressing images to grayscale for drones and mobile data transmission is one potential application, particularly considering that latency counts in drones use.
    - Exploring areas and applications to assist Color Vision Deficiency (CVD) community. There have been substitution systems developed for visually impaired persons to aid their mobility. The auditory augmentation systems, for instance, are in some cases used in combination with grayscale images to compliment the users' visual sense.

## **1.5 Research Delimitation**

Given that this research is performed as a master thesis work with limited time frame and resources, the following delimitation have been set to ensure the study scope and focus are on track:

- The navigation experience is limited to having the users follow the navigation directions presented in the experiment task, through the use of turn-by-turn navigation aids. It does not include users' path search, path selection activities, and other processes in the larger wayfinding context.
- The navigation experience is limited to indoor navigation and does not include outdoor navigation.
- The navigation experience does not include having users providing input to the MAR application to assist the navigation experience.

## **1.6 Research Assumption**

This study assumes that all the test participants in the research do not have CVD.

## Theoretical Background, Literature Review & Research Hypotheses

This chapter first presents different theoretical background and literature that serve as the building blocks for this study.

- Section 2.1 provides a basic understanding of augmented reality, mobile augmented reality (MAR), its applications, and the current state-of-the-art in MAR navigation.
- Section 2.2 introduces key concepts in navigation involving spatial knowledge and navigation aids.
- Section 2.3 summarizes the studies about color in augmented reality that are available in the literature.
- Section 2.4 gives a literature background about selective visual attention and the effect of color on selective visual attention.
- Section 2.5 presents key literature findings on gender differences in navigating in virtual environments.

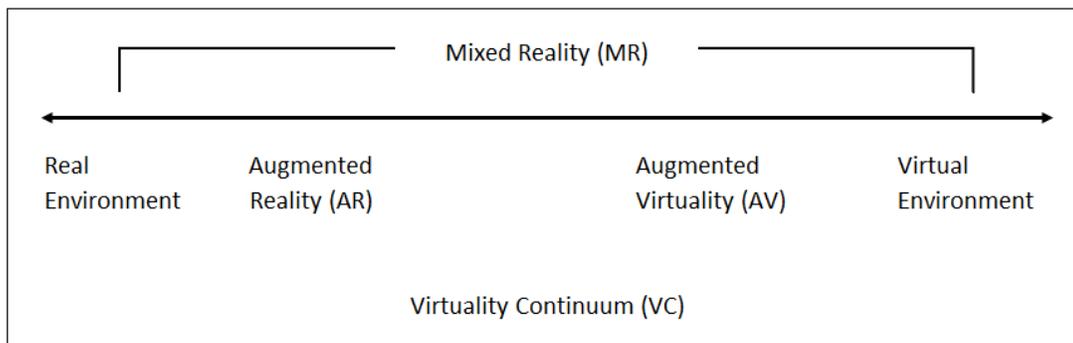
Following the literature summary, the hypotheses and the corresponding variables to be studied are introduced.

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## 2.1 Augmented Reality & Mobile Augmented Reality

### 2.1.1 Augmented Reality

Augmented Reality (AR) is the overlaying of computer-generated objects on top of the real-world environment. Milgram and Kishino (1994) discussed the concept of “having both ‘virtual space’ on the one hand and ‘reality’ on the other available within the same visual display environment”. They also suggested that the immersion experience falls in a “virtuality continuum” where one end of the continuum is the real-world environment and the other virtual environment consisting of virtually created objects (see Figure F2.1). In the same article, the authors defined Augmented Reality as the “computer graphic enhancement of video images of real scenes”.



**Figure F2.1:** Milgram’s “virtuality continuum”

Subsequently, in their survey about AR advances, Azuma et al. (2001) specified three properties that define AR:

1. the combination of real objects and virtual objects in a real environment
2. the real-time interaction capability
3. the alignment of virtual objects and real objects

In terms of hardware, AR consists of input devices, sensors, processors, and displays. Input devices are devices that support interaction with the AR application such as mouse pointer, stylus pointer, camera pointer, speech recognition, or body gesture recognition systems. Sensors hardware supports the tracking of orientation and position in an AR environment using sensors including optical sensors, digital camera sensors,

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GPS and accelerometers. Processors could be those of a computer or a mobile device to process the images captured by the camera. For displays, there are various types available and are under three main categories: spatial displays (e.g. video projectors, holograms), body-attached displays (e.g. head-mounted display, eyeglasses) and handheld displays (smartphones, tablets) (Carmigniani et al., 2011).

## **2.1.2 Mobile Augmented Reality (MAR)**

### **MAR**

MAR is AR using mobile devices. Smartphone capabilities have been greatly improved over the years and that sets a foundation for MAR to develop. A smartphone possesses hardware that is required to build an AR application: available camera to function as an input device and sensor, a display as well as processing power. More than that, a smartphone with its mobility also offers location-based computing and wireless communication capability (Hollerer, 2004).

### **MAR Components**

There are three components rendered in a MAR application: camera feeds, virtual objects, and application interface elements. The camera feeds capture the real world “scenes” while virtual objects are the augmentations generated on top of such real-world scenes. Application interface elements are menus, icons, and instructional texts rendered in the MAR application to guide users’ actions and interactions with the MAR application.

### **MAR Applications**

MAR has been used in various domains such as education, tourism, entertainment, and navigation. In education, MAR supports learning through interactive and visual depictions of objects that otherwise could not be achieved without the technology. For example, the ninth-grade students at a public school in Taiwan learned about radiation through the use of a MAR application which enabled them to collect the virtually-imposed radiation data, simulating the Fukushima Daiichi Nuclear Power Plant accident (Chang et al., 2013). Google Skymap is another educational MAR application that includes augmented information about the constellations when users point their camera to the sky (Wasko, 2013). In tourism, MAR is used to display

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additional information about landmarks and heritage destinations to tourists (Chung et al., 2015). Furthermore, a well-known example of MAR application in entertainment is the game Pokemon Go launch in 2016, which was “the first mobile augmented reality (AR) game to reach the top of the download charts of mobile applications” (Rauschnabel et al., 2017). On the retailing end, IKEA recently introduced its IKEA Place MAR application with which users could simulate how a piece of furniture would look like in their house using their mobile devices (Weinz, 2019).

### **2.1.3 AR/MAR Tracking Systems**

AR/MAR systems rely on the accuracy of their tracking to support navigation. The tracking provides information about the AR systems position and orientation relative to the real-world, in real-time (Paulo Lima et al., 2017). Two main types of popular tracking systems in use are marker-based tracking and markerless-tracking. Marker-based tracking requires the placement of fiducials on the scene through the use of, for example, QR code or bar code. The camera captures these fiducials and extracts position information. On the contrary, markerless-tracking does not need to have fiducial markers but relies on natural feature detection such as a plane or an edge detection (Brito & Stoyanova, 2018). Location-based tracking using the Global Positioning System (GPS) is one type of markerless tracking.

To solve the problem of GPS for indoor navigation using augmented reality, beacons were introduced. Beacons is a Bluetooth-based technology that provides location information in narrow spaces indoor. In 2017, London’s Gatwick Airport installed about 2000 beacons in its terminals with the vision to support an augmented-reality mobile application for route planning (Cannon, 2017).

## **2.2 Spatial Knowledge & Navigation Aids**

Three processes were suggested to be involved when an individual performed wayfinding or navigation tasks: forming a cognitive map, making navigation decisions, and executing navigation decisions (Chen & Stanney, 1999). In forming the cognitive map process, the navigator collected the knowledge of the navigating environment, which was termed spatial knowledge. Spatial knowledge involved the information about the navigator’s current location, the orientation and the direction. Spatial

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knowledge was often categorized into route knowledge, survey knowledge and landmark knowledge. Taylor and Tversky (1996) suggested route knowledge as descriptions from a first-person perspective while survey knowledge was in a larger perspective - a bird-eye view. The third category, landmark knowledge, was the description of the information about fixed and/or prominent objects or locations within the navigating scene.

Chen and Stanney (1999) proposed that the wayfinding performance was influenced by different factors and the effects were noted more in the cognitive map forming and the navigation decision making processes. Individual experience, the search strategies, and the spatial ability of the navigators were among the influencing factors.

To support the wayfinding and navigation, navigation aids were used. In literature, navigation aids were found to enhance the navigation experience differently in various navigation processes through the navigator's spatial knowledge. For instance, according to Chen and Stanney (1999), guided navigation aids were useful in the decision execution process where spatial knowledge was less required. Similarly, Gardony et al. (2013) suggested that route knowledge could be benefited through the use of turn-by-turn instruction navigation aids (as cited by Nguyen (2019)). Maps, arrow signs, and audio were the key categories of navigation aids outlined in the review by Nguyen (2019).

## **2.3 Color in Augmented Reality**

Published researches on color design for AR and MAR were rather limited. Gabbard et al. (2006) studied the effects of natural lighting, background texture, and text style on user performance in an augmented reality environment. Using an optical-see-through augmented reality system and 2D printed poster boards that resembled various natural outdoor backgrounds with different colors and textures, they evaluated user performance in a text identification task based on legibility. One of the findings from the study was that fully-saturated green labels in billboard styles are recommended over the use of red labels.

Resolving the problem of text and icon colors being “washed out” from the real-world background is one of the key areas studied in augmented reality. Also using an optical

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see-through display in their study, Gabbard et al. (2013) found that there were color washouts on display due to chromaticity and a linear shift of chromaticity. In the former, it was found that the color red is more saturated and vibrant in the no-lights condition and became desaturated against a white background. In the latter, all the colors were shifted towards the red side of the chromaticity diagram, e.g. yellow to orange, green to yellow. Gabbard et al. (2013) suggested that such a chromaticity linear shift could be problematic for user interface design where color encoding was critical.

In relation to that, Moffitt and Browne (2019) studied the visibility of symbols color. From their research on augmented reality using head-up and head-mounted devices, blue was identified to be a poor option for symbol both in low and high ambient. They found that in daylight condition, white, yellow, green, and cyan were the color set that performed better.

Also trying to address the color blending issue between the display color and the background, Hincapié-Ramos et al. (2015) proposed three strategies for color management through their SmartColor framework: correction strategy with real-time color correction, contrast strategy which preserved the hue as much as possible while providing high text legibility through a limited luminance, and show-up-on-contrast strategy where color was manipulated if related text content had poor contrast.

Aiming for visual aesthetic, Gruber et al. (2010) discussed color harmonization techniques on video-based augmented reality. They experimented on color shifting, or “re-color” of the real-world and virtual objects in order to achieve a visually pleasing outcome. They also introduced the concept of constrained color harmonization where the color shifting was not done for the colors that carry semantic meaning but was freely adjusted for other colors.

On a different end, Menk and Koch (2013) proposed a method to compute the color values of an image that was to be projected in a spatial augmented reality environment. In the context of the automobile design process, ambient light, projecting material as well as the pose and color model of a projector were considered. Considering the influences of these factors, the result of the study was a color mixing matrix and a physical-based computation that provided a closely accurate color projection of virtual objects in spatial augmented reality.

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## **2.4 Selective Visual Attention and Color Information**

### **2.4.1 Selective Visual Attention**

#### **Overt and Covert Attention**

Human's visual attention develops a mechanism to attain to the surroundings through a 2-stage process: illuminating the area of interest (pre-attentive stage) and processing information from such area (attentive stage). This concept of focal attention was first introduced by Neisser in 1967 (Neisser, 2014) where the author suggested that humans processed information as a whole of segregated objects at first to identify an area of focus before paying attention to a particular area of interest. Such a mechanism enables humans to process a visual scene by focusing attention on one region and shifting such attention to further explore another region. Overt attention and covert attention are the two ways through which focus attention was placed. In overt attention, eye movements happen and the attention focus is shifted to the target. On the other hand, covert attention occurs when information in the visual scene is processed without eye movements (Posner, 1980).

#### **Bottom-up and Top-down Attention**

There are two types of influences on visual attention: bottom-up influences and top-down influences. In bottom-up attention, the visual cues and characteristics of the scene drive attention; these are usually features or cues in the scene that are distinctive enough to catch the attention of viewers. In the top-down approach, attention is driven by the goal at hand. These two types of attention are also known as "scene-driven" and "expectation-driven" attentions respectively. Bottom-up attention is usually fast, involuntary and driven by visual cues in the scene while top-down attention is slow, voluntary and task-driven (Borji & Itti, 2013).

#### **Selective Attention Models**

There are many models of attention introduced in the field of human visual attention study. Among those related to selective attention are the models introduced by Koch and Ullman (1987) and Milanese et al. (1994). In Koch and Ullman's model, maps of elementary features such as color, orientation are formed in the early representation, termed a topographical representation. Such feature maps are later on mapped to a

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central location through a selective mapping process that focuses on a single location in the visual scene. Underlying the selective mapping process is the winner-take-all mechanism that identifies a conspicuous location on the saliency map and relays the information about this location to the central processing.

In the second model proposed by Milanese et al. (1994), bottom-up and top-down attention are integrated to enable the extraction and processing of visual scenes through reducing complexity. In this model, visual attention is benefited from two activities: (1) processing first a scene through bottom-up attention with low-level features such as color and curvature then build a conspicuity map; and (2) utilizing distributed associated memory to produce a top-down saliency map. The result of which is a saliency map containing bottom-up and top-down visual cues.

## **2.4.2 Color Information Effects on Selective Visual Attention**

Studying the effect of color information on images, Frey et al. (2008) experimented on different types of still images such as landscape, flower, animal, face, and rainforest. At the end of the study, it was noted that color features such as saturation and color contrast were “highly salient in images of the Rainforest” category. Additionally, for this “Rainforest” image category, fixation locations were found to be significantly higher for colored images compared to grayscale images. The study concluded that color information has an effect on saliency and eye movements for a particular type of image.

Extending such a study, Shahrabaki (2015) evaluated the eye movements in dynamic views under the influences of color information. An experiment was conducted with test subjects viewing multiple videos rendered with color and grayscale stimuli. Among the metrics under evaluation were the dispersions and number of clusters, the saccade amplitude, and the fixation duration. Different dynamic scenes such as night light outdoor, daylight outdoor, indoor, and urban roads were studied. Regarding the effect of color information, Shahrabaki found that the number of clusters of eye positions was slightly higher for color stimuli than for grayscale stimuli. Shahrabaki suggested that the color information might increase the number of salient regions in the viewed scenes. Additionally, such effect varied over the viewing time with the middle period having the highest effect.

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## 2.5 Virtual Environments & Gender Differences

In studying the differences between genders in navigating virtual environments, Vila et al. (2003) tracked their study subjects through the numbers of left turns or right turns taken, the time spent, the number of rooms visited as well as the order of rooms visited. The study suggested that gender had an influence on the tendency to turn left or right in the initial time a test subject was exposed to a VR environment and the gender effect decreased when the exposure time with the VR environment increased. Additionally, Dünser et al. (2012) found that males performed better than females in a navigation experiment using a map and another experiment using a combination of AR and 2D maps. This finding was aligned with previous studies by Castelli et al. (2008) and Tlauka et al. (2005).

However, in the same research, Dünser et al. (2012) found that the task completion time was the same for both genders in the task using AR alone. The differences were explained by the two genders' navigation strategies where males tended to rely on orientation strategies and survey knowledge while females were based on landmarks knowledge. Such indifference was also registered by Castelli et al. (2008) and Vila et al. (2003). Furthermore, Dünser et al. (2012) also observed that females did not rate the AR interface more favorable compared to males. More recently, examining the performance gap between genders, Munoz-Montoya et al. (2019) found that there was no difference between males and females in an object-locating task using AR. The results were the same for the map-pointing and recall tasks after the AR task. Based on the comments received from the test participants, the research authors proposed that gender indifference was due to the same spatial strategy employed. Both female and male groups were found to use a route-based strategy performing the AR task.

In another aspect, Coluccia and Louse (2004) hypothesized that gender differences arose in more complex tasks. In particular, the authors suggested that gender differences do not materialize when the orientation task does not demand high load Visuo-Spatial Working Memory (VSWM). The differences, on the other hand, emerge when the orientation tasks require higher load of VSWM.

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## Literature Summary & MAR Navigation

In terms of color use and color guidelines for AR and MAR, the current literature focuses on improving the rendering of virtual objects. The studies available are mainly about finding mechanisms to display virtual objects so that the objects look as natural as possible while at the same time having high legibility against the background. Few studies consider the camera feeds color rendering.

Furthermore, it could be seen from the color psychological studies that color gives saliency and increases salient regions in visual scenes. Color information has effects on human's selective visual attention. In reality, there are often multiple colors that exist in a real-world scene and these colors are captured in the camera feeds of MAR.

Gender wise, many studies in the early 2000s suggested that males perform better in navigation tasks in virtual environments while some more recent studies found no significant differences in gender performances. It was also suggested that gender differences emerge with higher load visuospatial working memory. These studies about gender differences in virtual environments revolve around the different navigation strategies and navigation aids in use as well as around task complexity. The gender difference study is less covered in terms of visual elements impacts and less so for MAR camera feeds rendering.

The literature review gives rise to a number of questions:

- Would the additional number of colors in a scene increase the salient regions to the point that it has an inverse effect on visual attention? In other words, would the co-existence of multiple colors in the camera feeds become distracting and affect the navigation experience using MAR?
- Would it be better to render the camera feeds in Grayscale mode so that the users' attention is captured on the signage and less on the camera feeds background scene? Consequently, the navigation task at hand is more focused and improved?
- At the same time, by rendering the camera feeds in Grayscale mode instead of Colored mode, does it affect the users' experience using MAR for navigation?
- Are there any gender differences in navigation effectiveness and user satisfaction between rendering camera feeds in Color and Grayscale mode?

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## 2.6 Research Hypotheses and Research Variables

Based on the previous sections, the following hypotheses were formulated.

### 2.6.1 Hypothesis 1 - Effectiveness

**Hypothesis 1 (H1):** Rendering the camera feeds in Grayscale mode provides more effective MAR navigation compared to Colored mode.

#### Research Variables

- Independent variables: rendering camera feeds in Grayscale mode, rendering camera feeds in colored mode.
- Dependent variable: effectiveness of navigation using MAR.

In this study, the “Effectiveness” variable is measured by the time taken to complete a given navigation task using MAR (details in Chapter 3 Methods).

### 2.6.2 Hypothesis 2 - User Satisfaction

**Hypothesis 2 (H2):** Rendering the camera feeds in Grayscale mode gives lower user satisfaction in MAR navigation as compared to Colored mode.

#### Research Variables

- Independent variables: rendering camera feeds in Grayscale mode, rendering camera feeds in Colored mode.
- Dependent variable: users’ satisfaction level.

In this study, the “users satisfaction level” is measured by the user’s rating of their experience performing the navigation task using MAR. It will be measured through two aspects: the ease to perform the navigation task (Easiness) and the enjoyable level (Enjoyability) (details in Chapter 3 Methods).

## Methods

### 3.1 Choices of Methods

A mix of Quantitative and Qualitative methods was used in this research. However, Quantitative analysis was the main method whereas the qualitative study was only adopted as secondary input, in the form of additional, optional comments from the research participants. The use of quantitative research provided a quantifiable data analysis whereas qualitative research gave additional insights from the participants. Both subjective data (through measurements) and objective data (through self-rating by research participants) were collected.

Questionnaires were used to collect research participants' responses about their demographics, their task performance as well as their rating from the navigation tasks experienced in the study experiment.

#### 3.1.1 Quantitative Study

##### **Measuring Effectiveness (Time Taken)**

The time taken for each of the participants to complete a navigation task was measured. According to Tullis and Albert (2013), time taken to perform a task was one of the key performance parametric to measure usability. The time taken to complete the navigation task was measured in seconds using an on-screen stopwatch. The clock-on was determined as the time the participant started the task. The clock-off was determined by the time the participant completed the task (more on the task description

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in Chapter 4 Research Experiment). The time taken to complete a navigation task was displayed on a screen to the research participants when they completed the task. The test participant would then note down the time and self-reported the time measurement as a response to the research questionnaire.

### **Measuring User Satisfaction**

At the end of each navigation task, research participants were asked to rate their experience in the form of a five-point Likert scale. In each of the questions for rating, a statement with a positive adjective related to the satisfaction level was included. The participants were requested to rate their experience from 1 to 5 points (with 1 being Strongly Disagreed, and 5 being Strongly Agreed). Related to User Satisfaction, each test participant was asked to provide a rating for two questions, which corresponded to two adjectives (EASY TO PERFORM and ENJOYABLE).

Such a rating approach was an adaption from Lund (2001) who proposed a questionnaire that included rating scales for four different categories of users' response on Usefulness, Satisfaction, Ease of Use and Ease of Learning. Combining with that, the adjectives used in the questionnaire were picked from the Product Reaction Cards proposed by Benedek and Miner (2002).

### **Statistical Tests**

Statistical tests were conducted to evaluate both hypotheses H1 and H2. For tests related to Time Taken, test samples with unusual differences in time taken between Colored mode and Grayscale mode (outliers) were identified and excluded from the data analysis. The following statistical tests were performed.

- **Effectiveness - Time Taken:** A paired samples t-Test was conducted to compare the time taken between navigation tasks in Colored mode and in Grayscale mode.
- **Effectiveness - Time Taken by Gender:** An Independent samples t-Test was performed to compare the time taken between Male and Female groups when performing navigation tasks in Colored mode and in Grayscale mode.
- **User Satisfaction - Easiness:** since the rating was done on Likert-scale (ordinal data), a Wilcoxon Signed Ranks test was performed to compare the Easiness of navigating in Colored mode and in Grayscale mode.

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- **User Satisfaction - Enjoyability:** similarly, since the rating was done on Likert-scale (ordinal data), a Wilcoxon Signed Ranks test was performed to compare the Enjoyability of navigating in Colored mode and in Grayscale mode.
  - **Overall Preference by Gender:** A Mann Whitney U-Test was performed to compare the Overall Preference rating of the Female and Male test participants for Colored mode versus Grayscale mode. The rating was on a five-point Likert scale and data were ordinal.

IBM SPSS was used for data analysis.

### 3.1.2 Qualitative Study

Free text input in the form of optional comments was included in the questionnaires so that participants could share their feedback or comments about their experience performing the given navigation tasks. Thematic analysis was performed on the data obtained from these comments with an inductive approach where the themes emerged from the comments data.

Specifically, the researcher read through all the comments received then coded, or highlighted, the important texts and phrases. These were afterwards translated into different main themes that shared data patterns. Prior to that, service by Tagcrowd (<https://tagcrowd.com/>) was also used to generate a words cloud of the comments keywords. Such a tool provided a quick, visual view of the repeated keywords from the comments.

## 3.2 Research Participants

Research participants were recruited through “convenience sampling” on a voluntary basis. The targeted age range for recruitment was from 18 to 40 years old. That is because the people in this age range are generally familiar with technology and mobile phone use. The target number of research participants was 30 for normal distribution. The number of males and females participants was targeted to be equivalent or near equivalent so that gender bias could be reduced.

## Research Experiment

### **4.1 Originally Planned versus Actually Conducted Experiment**

#### **Originally Planned Experiment**

Originally, the experiment was designed to be tested on a mobile phone using a MAR application prototype, with the test participants perform navigation tasks in an actual physical setup such as a library. However, while the experiment preparation was in progress, the experiment was changed from testing in person using MAR prototype to testing remotely online using an on-screen simulated environment.

The main reason for the experiment change was due to the unforeseen circumstance of the Corona disease (COVID-19) where social distancing was enforced; the school was locked down and thus recruiting test participants as well as conducting the experiment in person was not feasible. At the time this experiment change decision, the preparation for the MAR application prototype was in progress. The work related to MAR mobile prototype that was completed at that point includes the designing of 3D signage, placing signage in the prototype, setting up MAR application Colored and Grayscale mode. In finetuning the MAR application prototype, there was a small technical problem encountered with deploying the prototype to a mobile phone due to a device compatibility issue after an operating system upgrade.

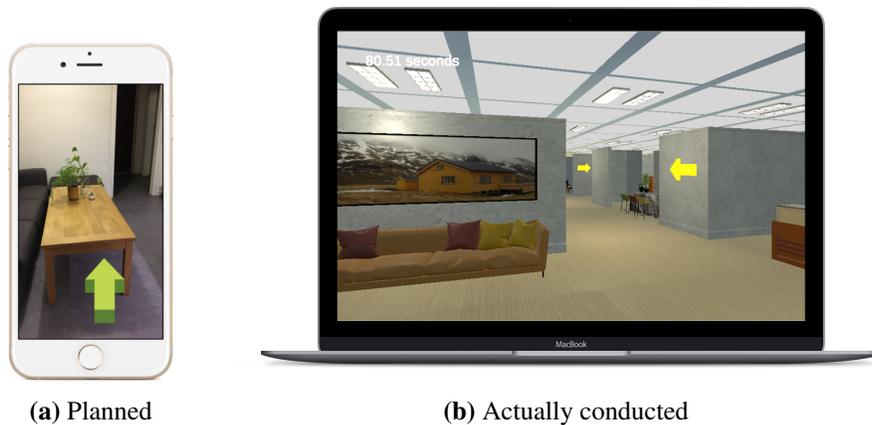
Coupling with the COVID-19 situation, a decision was made to switch the experiment

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to an on-screen simulated environment, rather than spending time on troubleshooting the MAR app prototype with uncertainty about the lock-down situation, which consequently would jeopardize the study schedule.

## Actually Conducted Experiment

The actual experiment set up for this study was designed as an on-screen environment that simulated the indoor view of an office building. The set up environment resembled a computer-game, virtual environment and the test participants can “walk around” and perform navigation tasks to a target destination in this environment. The target destination was set as a penguin object. The test participants needed to use a laptop or a desktop computer to navigate the environment with the combination of mouse and keyboard arrows to move around.



**Figure F4.1:** Originally Planned experiment vs Actual experiment

Table T4.1 summarizes the key differences between the originally planned setup (with physical MAR application) and the actual experiment setup (with the on-screen simulated environment).

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	<b>Originally Planned Experiment</b>	<b>Actually Conducted Experiment</b>
Platform	On-site in person	Online survey
Device	Mobile	Computer
Task Design	Indoor (Library), physical movement task using MAR application	Indoor (Office), on-screen computer task
CVD Test	Yes (Ishihara’s CVD test)	No
Data	Researcher-administered and self-report	Self-report
Technology	Apple ARKit	Unity

**Table T4.1:** Originally Planned vs Actually Conducted Experiment

## 4.2 Test Participants Recruitment

The research participant recruiting was done through convenient sampling via the social media platform Facebook through a Google survey form. The URLs to the Google Forms were posted on the researcher’s Facebook profile and were also shared in the International Students in Gjøvik chat group. In total, there were 30 test participants taking part in the experiments.

## 4.3 Experiment Tasks

Each participant was requested to perform two navigation tasks in an on-screen environment which simulated an indoor environment, in particular, an office building. The test participants were asked to follow the directional instructions given by the navigation aids (signage) on-screen. The navigation tasks were designed to be simple indoor navigation tasks within the context of an office building.

In one task, the office environment was rendered in Colored mode, and in the other task, the environment was rendered in Grayscale mode. Navigation distance and complexity were arranged to be similar between the task in Colored mode and the task in Grayscale mode.

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## 4.4 Experiment Procedure

Google Form was used as an online survey to recruit test participants as well as to collect their task performance and responses. As a result, the use and design of the Google Form depicted the experiment procedure. The procedure of the experiment was documented in the subsequent section. This was also the order of information presented in the Google Survey Form (see Appendix A).

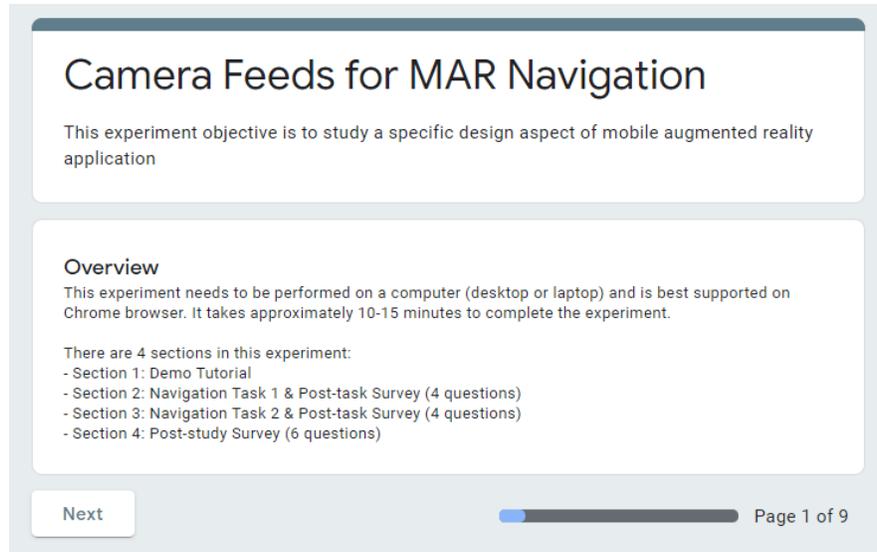
The high level of the Experiment Procedure was as follows:

- Present to test participants the Experiment Overview.
- Present to test participants the Data Collection & Confidentiality. Obtained their consent for data collection, processing, and storage.
- Test participants to perform Demo Tutorial to get familiar with the environment.
- Test participants to perform Navigation Task 1 and complete the Post-task Questionnaire.
- Test participants to perform Navigation Task 2 and complete the Post-task Questionnaire.
- Test participants to complete the Post-study Questionnaire.

The following sections present the procedure in detail.

### 4.4.1 Experiment Overview

Upon clicking on the Google Survey Form URL, a test participant would be directed to the Welcome screen of the survey, with an Overview of the Experiment.



**Figure F4.2:** Experiment survey form - Welcome screen

## 4.4.2 Data Collection and Confidentiality

The test participant would then be presented with information about data collection and confidentiality.

- Information about how data was to be collected, processed, and stored.
- Information about data confidentiality.
- Information about the test participants' rights for confidentiality and the rights to withdraw from the study.
- Contact information for queries related to the experiment.

Personal information that could be used to identify a person such as names, telephone numbers or social securities was not collected.

Following that, the test participants were asked to provide their consent to data collection, processing, and storing. Consent was sought before they took part in the study. The Letter of Information and Consent Form can be found in Appendix B.

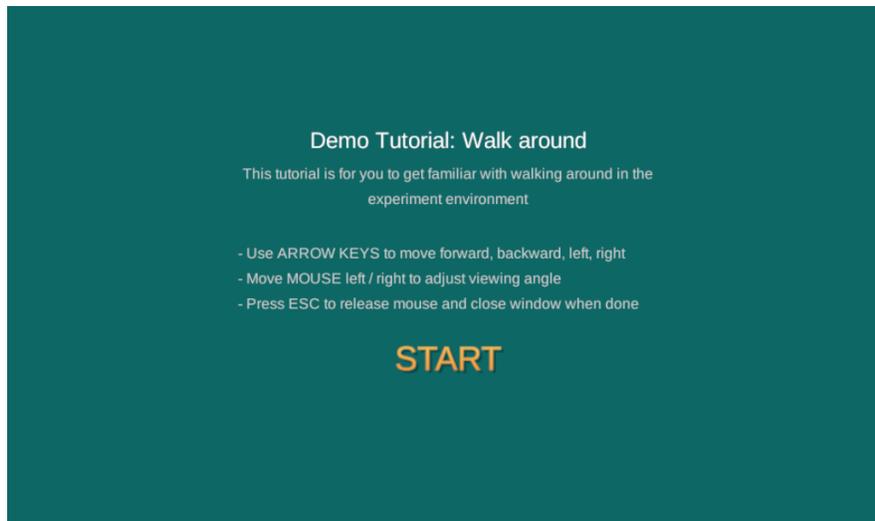
## 4.4.3 Demo Tutorial Task

The test participants would then be presented a Demo task through a hyperlink. Upon clicking on this hyperlink, test participants could perform a simple navigation test in a

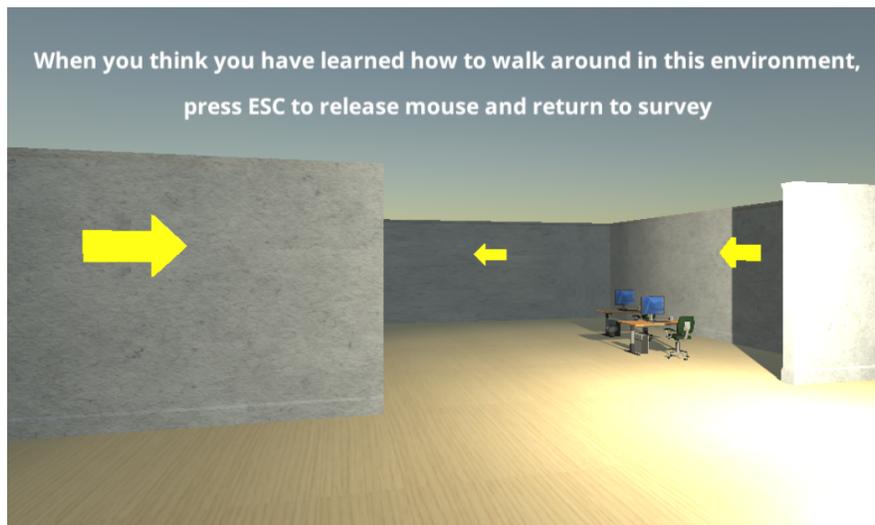
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demo environment that was built to be similar to the actual navigation task environment.

The objective of this demo task was for test participants to be familiar with the test environment as well as navigating in such an environment. The demo included guides on how to navigate in the testing environment. Test participants could spend as long as they wanted on this Demo Tutorial.



**Figure F4.3:** Demo tutorial - Welcome screen with guides



**Figure F4.4:** Demo tutorial - Environment screenshot

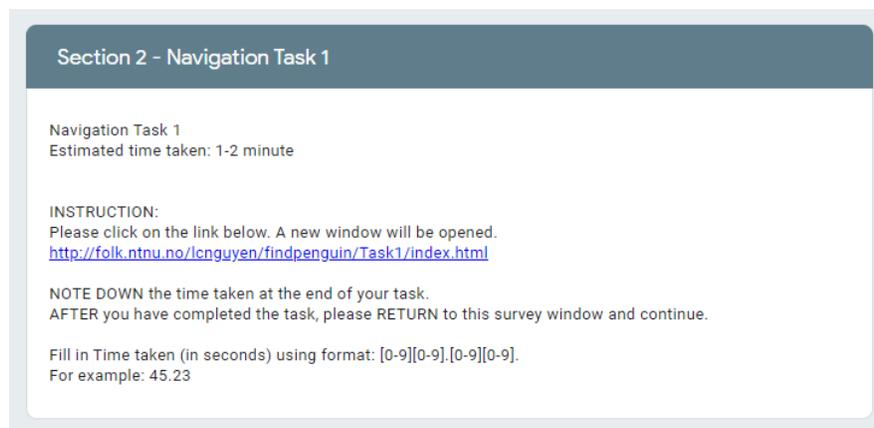
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## 4.4.4 Navigation Task 1 & Post-task Questionnaire

### Navigation Task 1

After the Demo Tutorial task, test participants were presented information about Navigation Task 1 with the below information:

- Instructions.
- URL to task environment which is a Unity built environment and was opened in a new window.



**Figure F4.5:** Navigation task - Instructions and URL

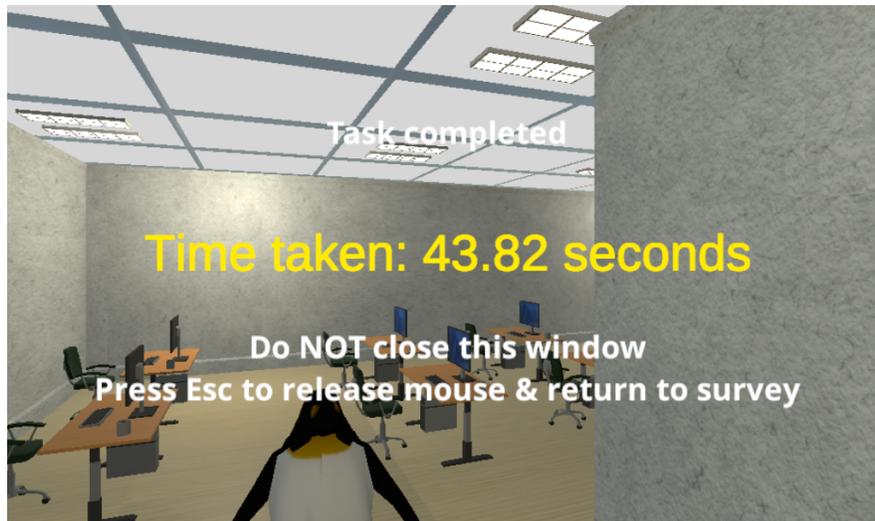
### Post-task Questionnaire

After the test participant completed Task 1, there was an on-screen instruction to go back to the Google Form Survey to complete the Post-task questionnaire. The Post-task questionnaire included four questions covering below four points. More details about the questions can be found in section 4.5 Survey Questionnaires.

- Time taken to complete the task
- Easiness rating
- Enjoyability rating
- Any additional comments the test participant might have

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Easiness and Enjoyability were measured on a 5-point Likert scale, with 1 being “Strongly Disagree” and 5 being “Strong Agree”.



**Figure F4.6:** Navigation task - Time taken recorded

#### **4.4.5 Navigation Task 2 & Post-task Questionnaire**

Procedure and information for Navigation Task 2 were similar to that of Navigation Task 1. However, if Navigation Task 1 was in Colored mode, Navigation Task 2 would be in Grayscale mode and vice versa. This environment order alternating was a counterbalancing method as presented in section 4.7 Experiment Design Considerations.

#### **4.4.6 Post-study Questionnaire**

When a test participant completed both Navigation Task 1 and Navigation Task 2 and the corresponding Post-task Questionnaires, there was a Post-Study Questionnaire asking the test participant for:

- Overall preference rating between Task 1 and Task 2
- Any additional comments about the experiment in overall
- Demographic information (Age, Gender)

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## 4.5 Survey Questionnaires

This section presents in details the three questionnaires that were administered for each of the test participants:

1. **Post-task Questionnaire - for Colored mode task:** The questionnaire was used to collect participants' ratings and feedback about the navigation experience after performing the navigation task in Colored mode. The Post-task Questionnaire contained four questions that asked for:
  - Time taken to complete the task: to be self-reported by the test participant based on the time recorded and displayed on-screen in the test environment when the test participant completed the task. The time taken was registered in seconds, and in xx.yy format, e.g. 14.24 seconds.
  - Easiness rating of how the test participant found the navigation experience, measured on a 5-point Likert scale, with 1 being "Strongly Disagree" and 5 being "Strong Agree"
  - Enjoyability rating of how the test participant found the navigation experience, measured on a 5-point Likert scale, with 1 being "Strongly Disagree" and 5 being "Strong Agree".
  - Any additional comments the test participant might have in free text-field. This would be used for Qualitative analysis.

The Post-task Questionnaire contained the following statements:

- Overall, I find the navigation experience in Task [1 or 2] EASY TO PERFORM
- Overall, I find the navigation experience in Task [1 or 2] ENJOYABLE.

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Section 3 (cont.) - Post-task 2 Survey

Please indicate your evaluation of the navigation experience.

Q6/ Overall, I find the navigation experience in Task 2 EASY TO PERFORM \*

1 2 3 4 5

Strongly Disagree      Strongly Agree

Q7/ Overall, I find the navigation experience in Task 2 ENJOYABLE \*

1 2 3 4 5

Strongly Disagree      Strongly Agree

**Figure F4.7:** Post-task questionnaire - Sample questions

- 2. Post-task Questionnaire - for Grayscale mode task:** this questionnaire was the same as the Post-task Colored mode Questionnaire but was administered after participants completed the Grayscale mode task.
- 3. Post-study Questionnaire:** this questionnaire was to be completed at the end of both navigation tasks in Colored and Grayscale mode. There was one question asking the participant to indicate their overall preference to either Grayscale or Colored mode in a five-point Likert scale. A free form comment space was also provided so that the test participants could give additional insights. Additionally, there were also two questions asking the test participants to provide their general demographic information in terms of gender and age.

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The image shows a screenshot of a questionnaire interface. The top section contains question Q9: "Overall, I think the navigation experience is \*". Below the question is a horizontal row of five radio button options. The labels above the radio buttons are: "Much better in Task 1", "Slightly better in Task 1", "Neither one is better", "Slightly better in Task 2", and "Much better in Task 2". The first option, "(select one)", is highlighted with a light blue background. Below this is question Q10: "Any additional comments you might have", followed by a text input field labeled "Your answer".

**Figure F4.8:** Post-study questionnaire - Overall preference rating question

## 4.6 Experiment Testing Environment

The environment that was set up for the experiment testing was an indoor simulation of an office building. Test participants can “walk around” and perform navigation to a target destination in this navigation scene. The target destination was set as a penguin object. The navigation scene was designed with Unity build version 2018.4.19f1. The scene consisted of:

- Scene setup: rooms, hallways, furniture, floor, ceiling, and lighting.
- First-person view: there was no virtual representation of the test participant in the office scene in terms of body or object. The test participant was represented with a first-person point of view when he or she looked out of the scene.
- Directional signage: arrows that functioned as the navigation clues to guide the test participants towards the target destination.
- Target destination: marked with an animated penguin. An animation object was selected to ensure that the target destination was easy to be recognized regardless of whether the scene was rendered in Colored or Grayscale mode.
- C# Scripts: to measure the time taken to perform the task and to display the texts.



**Figure F4.9:** Scene design - Office furniture setup

## 4.6.1 Scene Setup

### The Colored Mode Scene

The office floor area was 36 units x 45 units, with one unit represented a grid square unit in the Unity setup. Free 3D models with Royalty-Free Licenses were downloaded from Unity Asset Store (<https://assetstore.unity.com/>) and other free 3D websites such as TurboSquid (<https://www.turbosquid.com/>), CGTrader (<https://www.cgtrader.com/>) and Clara (<http://clara.io/>). Some downloaded objects were re-colored in order for them to be colorful and visible in the scene using Autodesk 3dsMax software (<https://www.autodesk.com/products/3ds-max/overview>). The list of the 3D models used can be found in Appendix C.



**Figure F4.10:** Scene design - Unity top view with grid displayed



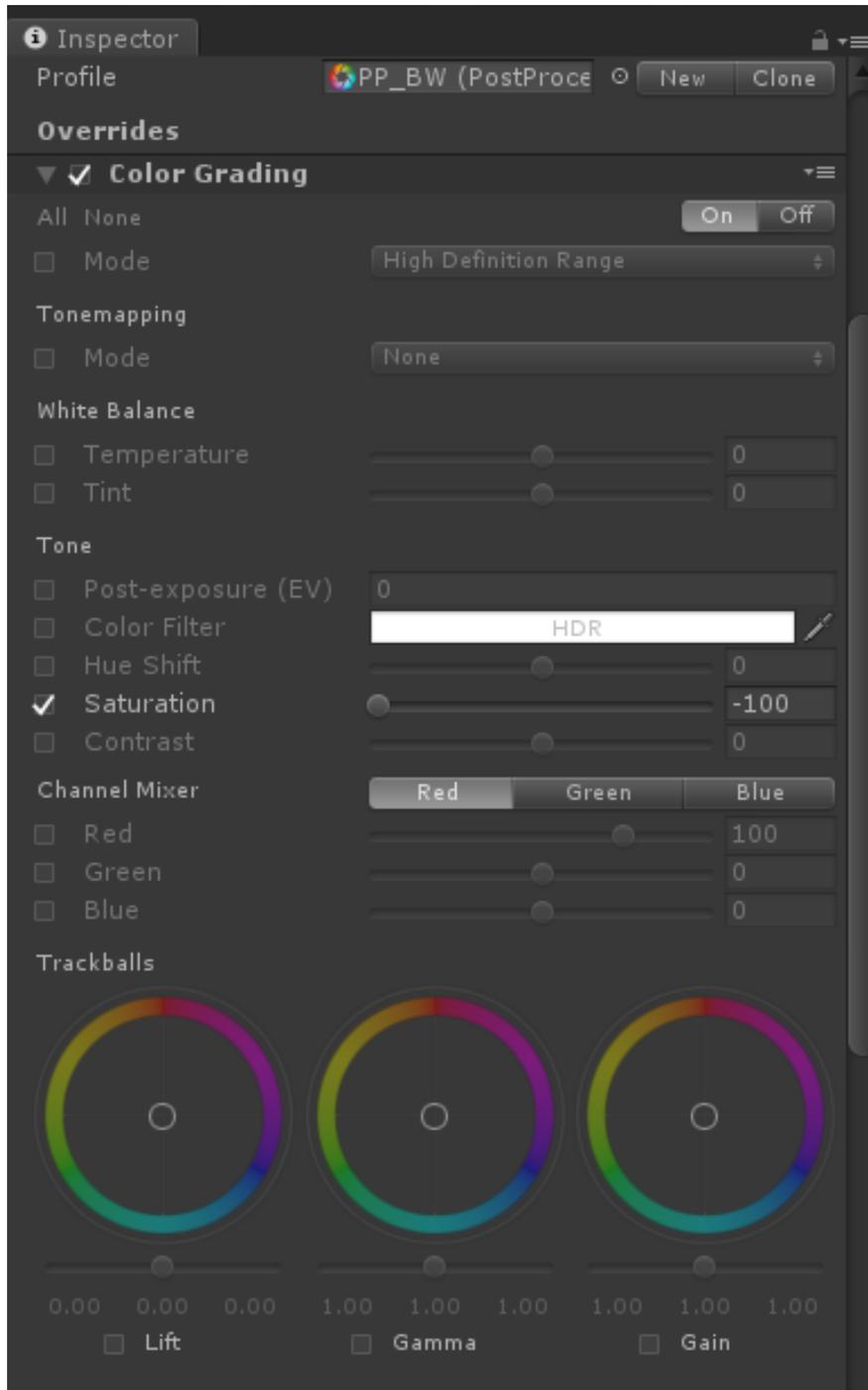
**Figure F4.11:** Scene design - Signage along the wall

### **The Grayscale Mode Scene**

The Grayscale scene was created with a similar set up as the Colored mode scene, except that the scene background was desaturated. To desaturate the scene, the Post Processing Profile of Unity was used, in particular, the Color Grading feature. The

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saturation level was set to -100 in Unity setting, which was the lowest level of saturation in Unity.



**Figure F4.12:** Scene design - Unity color grading settings

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## 4.6.2 First-person View

This utilized the built-in FirstPersonCharacter module of the FPSController package within Unity (the controlling script was Unity FPSController.cs). The module provided a viewpoint from a first person's perspective based on a camera object placed in the scene. Test participants could control the movement of the first-person by using arrow keys on their keyboards. By moving their mouse left or right, the test participants could expand their view horizontally for a wider view angle.

The default setup of Unity built-in the first-person view was kept in terms of Field of View and Viewport.

The camera position was adjusted to the position of 1.8 unit from the ground so that the eye-level of the first person was more natural (as compared to the default eye-level of Unity which was at a lower position, looking down towards the ground). Additionally, the vertical rotation of the first-person was also disabled (Clamp Vertical Rotation setting in Unity). That was done to avoid the distractions the test participants might have with moving their mouse up and down and accordingly impacted the time taken to perform the navigation task.



**Figure F4.13:** Scene design - Unity first-person camera view

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### 4.6.3 Directional Signage

3D virtual directional signage was included and layered on top of the virtual navigation scene setup. This 3D directional signage was designed in the form of directional arrows. Test participants were to follow these arrows to navigate towards the target destination.

The arrows were placed on the wall, at the eye-level of the test participant's point of view in the scene. The arrows were placed in such a way that they would be visible before the navigation decision point (e.g. turn left or turn right). Such a placement position allowed the test participants to know in advance the direction they needed to follow from a given distance.



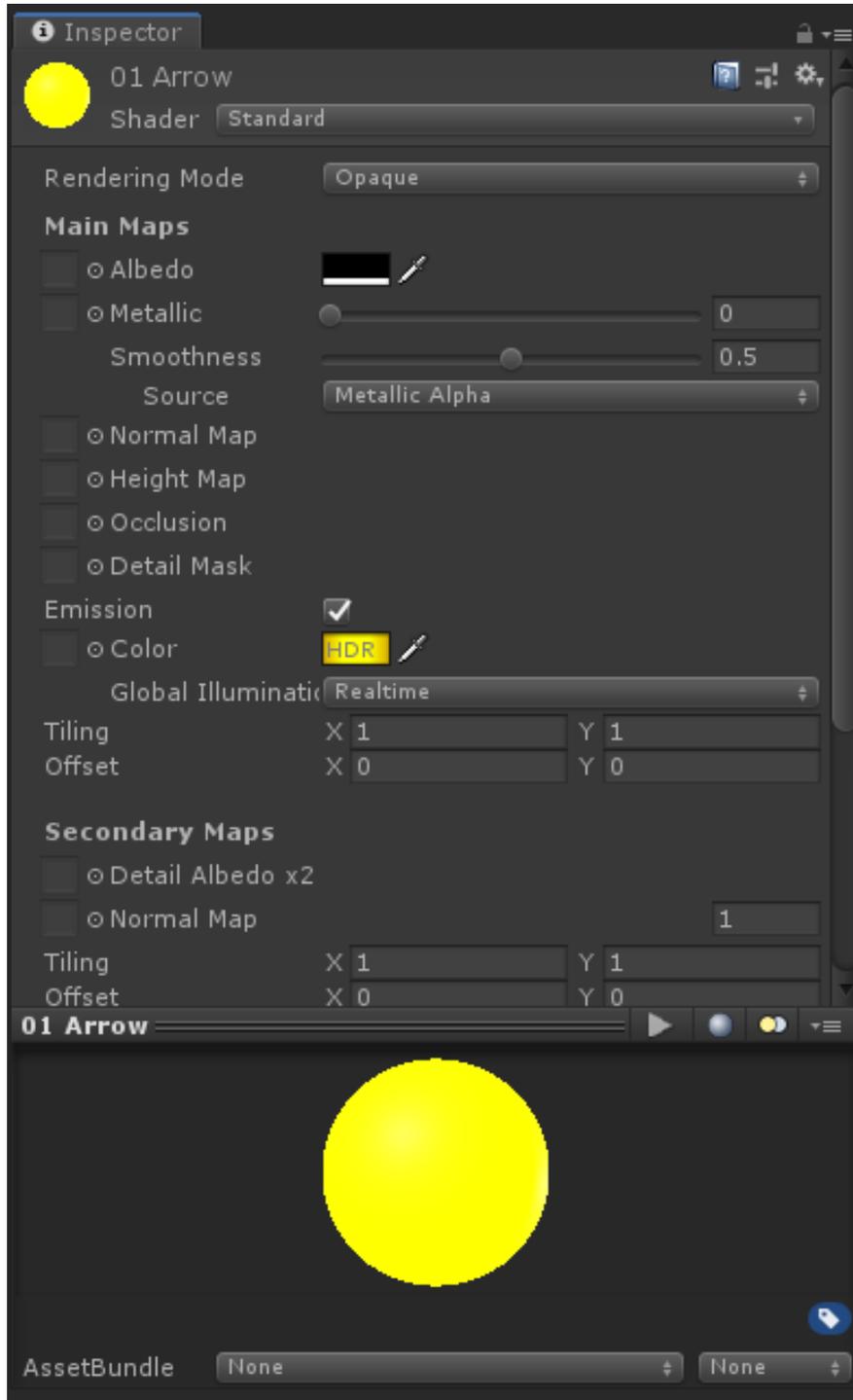
**Figure F4.14:** Scene design - Signage in Colored environment



**Figure F4.15:** Scene design - Signage in Grayscale environment

The signage arrows were designed with highly vibrant yellow color (HEX value: #BF7B00). Yellow is often used in road signage since it not only provides good contrast and visibility from a distance but also is less likely to impact people with CVD as compared to red and green. Additionally, the signage arrows were also added with Unity “Emission” and “Intensity” settings. Such design allowed the arrows to stand out from the background scene, both in Colored mode and Grayscale mode. Signage arrows were not desaturated in the Grayscale mode task.

In order to have the background scene desaturated and the directional signage visible in color at the same time, layering of camera views were done in Unity – one camera to render the background scene in Grayscale, the other rendered the arrows in color.



**Figure F4.16:** Scene design - Signage appearance settings

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#### 4.6.4 Target Destination

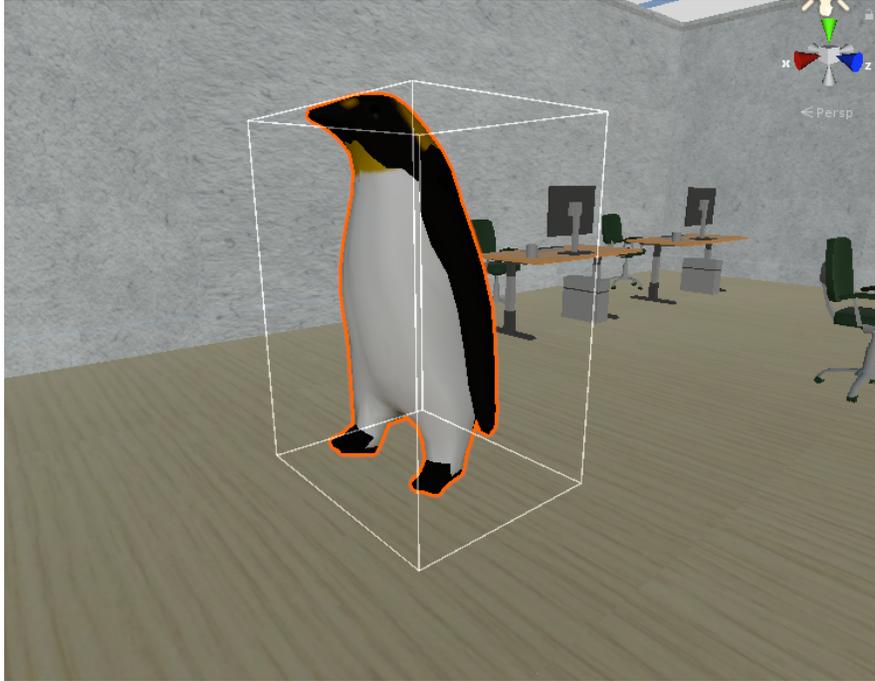
An animated penguin was selected to be used as the marked target destination.

The selected penguin was a free 3D object available in the Unity Asset Store. Unlike other elements in the scene, an animated object (the penguin) was selected as the target so that it will stand out from the scene setup and thus reducing any impact by color choice it might have in Colored and Grayscale mode. Additionally, a penguin could also be an appropriate object to be set on the ground for test participants to easily find and reach with their walking position, as opposed to, for example, a picture frame that was hung high above on the wall.

A “collision” area, or a box area drawn around the penguin, was created. The collision was used to determine the point that the test participant reached the target. As soon as a test participant reached this collision box, a script will be triggered to stop the time measurement and the task was considered completed. With the collision, the distances from the penguin that the test participants must reach to complete the task were the same. Thus, the collision helped to set a clear task ending point for all test participants. As part of the task instruction, the test participants were informed that the task would be completed and the time-watcher would stop when they reached close enough to the penguin.



**Figure F4.17:** Scene design - Penguin as target destination



**Figure F4.18:** Scene design - Penguin with collision area

#### 4.6.5 C# Scripts

There were two C# scripts used for this experiment. One was the built-in FPSController.cs script and the other was Timer.cs. The FPSController.cs was modified to include the control of the collision (the completion of navigation task). The Timer.cs script was a new script additionally written to measure the time taken to complete the navigation task and to display the texts in the scene.

#### Summary of Tools and Technologies Used

- General scene setup: Unity 2018.4.19f1
- 3D modelling: free 3D models, Unity 2018.4.19f1 and Autodesk 3DsMax
- First-person character movement: C# scripts
- Time Measurement and texts display: C# scripts

A footage video showing an example of the experiment environment navigation could be found in Appendix C.

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## **4.7 Experiment Design Considerations**

### **4.7.1 Colored vs Grayscale Scene**

To measure the research variables, other elements in the scene setup needed to remain the same between the Colored scene and Grayscale scene. The two scenes were identical in terms of furniture used, walking spaces, and walking distances towards the target destination (the penguin). The only key difference was the fact that the background scene was desaturated in the Grayscale scene according to the objective of this research.

Nonetheless, there was some slight variance introduced to reduce the “learning effect” where the test participants gained knowledge of the target destination after performing one task and may affect the second task performance.

Firstly, the furniture placement was slightly different between the two scenes. For example, a billiard board could be placed at position A in the Colored scene and in the Grayscale scene, a table was put in the same position A. However, the furniture and number of furniture used in the scenes were the same.

Furthermore, the travelling routes were also set to be symmetrical between the two scenes. That means the traveling routes between navigation task 1 and navigation task 2 were in opposite directions but had the same number of turns and travel distances. For instance, if an arrow pointed right (for turning right) in the Colored mode scene, it would be set up to point left in the Grayscale mode scene. Similar to the furniture placement, this opposite direction was intentionally done to reduce the learning effect of test participants knowing the walking path.

The signage and the penguin target destination were not desaturated in both environments.

### **4.7.2 Counterbalancing with Two Google Form Sets**

In normal experiments with physical setup, to avoid the “learning effect”, counterbalancing is usually done by changing the order of the task execution for the participants. In this study, since the experiment was done online, to achieve such

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counterbalancing, two sets of Google forms were used.

One set of Google form had the Colored mode task appeared first as Task 1 (and Grayscale mode task as Task 2) and the other set had a reversed order. 15 responses were collected for each of the set and the survey forms were closed when this number of responses was reached. In total, 30 responses were collected.

Accordingly, half of the test participants performed Colored mode first and the other half performed Grayscale mode first. Table T4.2 provides an illustration of such counterbalancing.

	<b>Task 1</b>	<b>Task 2</b>
Participant 1	Colored mode	Grayscale mode
Participant 2	Colored mode	Grayscale mode
Participant 3	Grayscale mode	Colored mode
Participant 4	Grayscale mode	Colored mode

**Table T4.2:** Counterbalancing - Task execution order

The data collected from the second form set was then re-coded to match the task order of that in the first set. After that, the two Google form sets data were merged into one dataset with 30 responses for the data analysis.

### **4.7.3 Use of Demo Tutorial**

The Demo Tutorial task was arranged so that the research participants could get familiar with the experiment setup before they performed the two actual navigation tasks. The use of Demo Tutorial was put in place for two objectives. Firstly, the Demo Tutorial would help reduce the effects of interface familiarity among research participants - between those with more and those with less or without computer gaming experience. This consideration was aligned with the finding presented in the literature review section about interface familiarity. Secondly, the Demo Tutorial was also meant to reduce the surprises a research participant might have if he or she started the actual navigation task without the Demo, which could introduce a performance gap between the two actual navigation tasks.

## Results

### 5.1 Demographics

In total, 30 responses were received for the experiment. Out of which, 63.3% were Females and 36.7% were Males.

90% of the participants indicated that they completed the Demo Tutorial Task.

Besides, 93.3% of the test participants navigated a similar environment before this experiment. On a 5-point Likert scale with 1 being Not familiar at all and 5 being very familiar, 90% of the participants rated a point of 3 or more.

In terms of Age, the mean value for test participants' age was 26.9 with the minimum age of 20 and the maximum age of 37 (standard deviation of 3.845).

### 5.2 Quantitative Analysis

#### 5.2.1 Time Taken

##### Identifying and Addressing Outliers

Outliers are test samples with unusual values from other data points. Identifying and excluding outliers from the data analysis can help to avoid the analysis distortions and statistical power decrements caused by the outliers. From the experiment data set, a variable called Time\_Difference was introduced to identify outliers of samples that have

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an unusual value difference between the time taken to complete the navigation task in Colored mode and the time taken to complete the navigation task in Grayscale mode. A boxplot was performed on the Time\_Differences, and standard scores (z-score) was calculated for the corresponding Time\_Difference values (ZTime\_Difference variable). A cut-off value of +/-2 was used to filter out the outliers. As a result of this exercise, 1 sample case (case 18) was identified as an outlier and not included in the data analysis related to Time Taken.

### **Time Taken - Colored mode versus Grayscale mode**

A paired samples t-Test was conducted to compare the Time Taken to complete the navigation task in Colored mode and the Time Taken to complete the navigation task in Grayscale mode.

The results showed that there was not a significant difference between the time taken to complete the navigation task in Colored mode (M=29.53, SD=28.17) and the time taken to complete the navigation task in Grayscale mode (M=26.87, SD=21.73);  $t(28)=.90$ ,  $p=.376$ .

The null hypothesis of H1 cannot be rejected, and the alternative hypothesis H1 cannot be accepted. Together, the results suggested that, for Effectiveness (Time Taken), the test subjects equally performed the navigation in Grayscale mode and Colored mode .

### **Time Taken by Gender**

Independent sample t-Tests were performed to compare the difference in time taken to complete the navigation task between Male and Female groups. The tests were performed for Time Taken in Colored mode and time taken in Grayscale mode (see Tables T5.1).

The results suggested that:

- There was not a significant difference in time taken to complete the navigation task in Colored mode between Male (M=17.95, SD=7.59) and Female (M=36.60, SD=33.66);  $t(27)=-1.798$ ,  $p=.083$ .
- There was not a significant difference in time taken to complete the navigation

task in Grayscale mode between Male (M=19.20, SD=6.44) and Female (M=31.56, SD=26.31);  $t(27)=-1.520$ ,  $p=.140$ .

	t-test for Equality of Means						
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
TimeTaken_Colored	-1.798	27	.083	-18.655	10.37647	-39.94562	2.63592
TimeTaken_Grayscale	-1.520	27	.140	-12.360	8.13079	-29.04285	4.32315

**Table T5.1:** Time Taken by Gender - Independent samples t-Test

## 5.2.2 Easiness

A Wilcoxon Signed-Ranks test was conducted to compare the Easiness of navigating in the Colored environment and navigating in the Grayscale environment. The test was performed on 30 test samples, i.e. without excluding the sample with Time Taken outlier value (cases 18).

The mean values of Easiness for Colored and Grayscale tasks were 4.47 and 4.4 respectively. There were 3 out of 30 test participants indicated that they found the Colored mode easier to navigate (Negative Ranks) while 2 out of 30 indicated that the Grayscale mode was easier (Positive Ranks). 25 other test participants did not find any difference in terms of Easiness navigating the two environments (see Table T5.2).

The Wilcoxon Signed-Ranks test results showed that the difference in the Easiness between navigating in Colored mode and navigating in Grayscale mode was not statistically significant ( $Z=-.707$ ,  $p=.480$ ). The median rating score was 5.0 for both conditions.

		N	Mean Rank	Sum of Ranks
Easiness_Grayscale - Easiness_Colored	Negative Ranks	3 <sup>a</sup>	3.33	10.00
	Positive Ranks	2 <sup>b</sup>	2.50	5.00
	Ties	25 <sup>c</sup>		
	Total	30		

a. Easiness\_Grayscale < Easiness\_Colored

b. Easiness\_Grayscale > Easiness\_Colored

c. Easiness\_Grayscale = Easiness\_Colored

### Test Statistics<sup>a</sup>

	Easiness_Grayscale - Easiness_Colored
Z	-.707 <sup>b</sup>
Asymp. Sig. (2-tailed)	.480

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

**Table T5.2:** Easiness - Wilcoxon signed tanks test

### 5.2.3 Enjoyability

A Wilcoxon Signed-Ranks test was conducted to compare the Enjoyable level of navigating in the Colored environment and navigating in the Grayscale environment. The test was performed on 30 test samples, i.e. without excluding the sample with Time Taken outlier value (case 18).

The mean values of Enjoyability for Colored and Grayscale tasks were 3.77 and 3.67 respectively. There were 8 out of 30 test participants indicated that they found the Colored mode easier to navigate (Negative Ranks) while 6 out of 30 indicated that the Grayscale mode was easier (Positive Ranks). 16 other test participants did not find any difference in terms of Easiness navigating the two environments (see Table T5.3).

The results showed that the difference in Enjoyable rating between navigating in the Colored mode and navigating in the Grayscale mode was not statistically significant

( $Z=-.632$ ,  $p=.527$ ). The median rating score was 4.0 for both conditions.

		N	Mean Rank	Sum of Ranks
Enjoyability_Grayscale - Enjoyability_Colored	Negative Ranks	8 <sup>a</sup>	7.75	62.00
	Positive Ranks	6 <sup>b</sup>	7.17	43.00
	Ties	16 <sup>c</sup>		
	Total	30		

a. Enjoyability\_Grayscale < Enjoyability\_Colored

b. Enjoyability\_Grayscale > Enjoyability\_Colored

c. Enjoyability\_Grayscale = Enjoyability\_Colored

### Test Statistics<sup>a</sup>

	Enjoyability_Grayscale - Enjoyability_Colored
Z	-.632 <sup>b</sup>
Asymp. Sig. (2-tailed)	.527

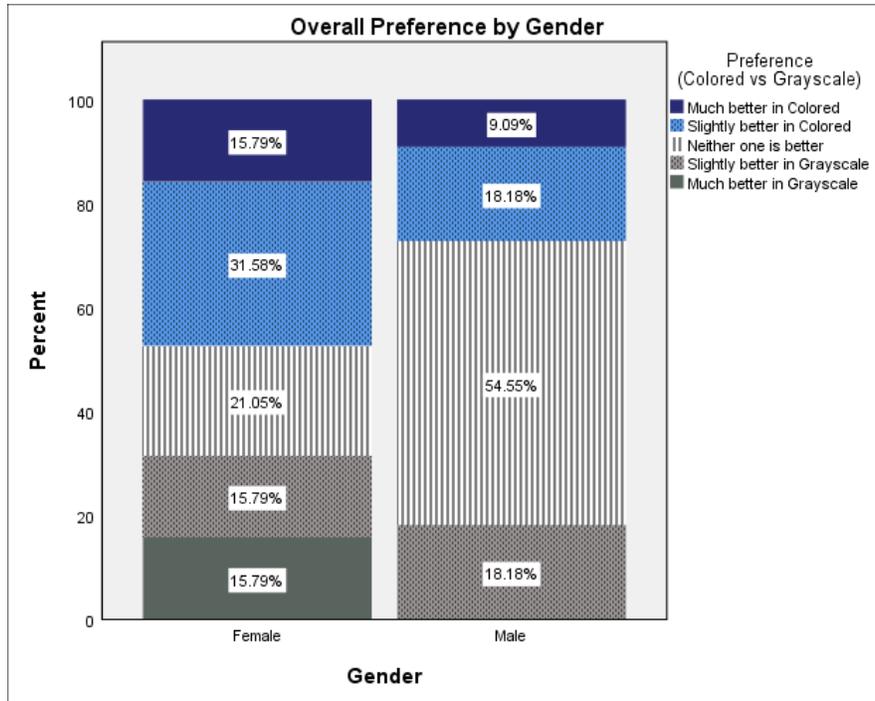
a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

**Table T5.3:** Enjoyability - Wilcoxon signed ranks test

## 5.2.4 Overall Preference by Gender

In rating the Overall Preference for Colored versus Grayscale task (Post-study question 9), the Female group showed a preference for both Colored mode and Grayscale mode, with 21.05% of the same group did not rate any of the two modes better than the other. On the other hand, the Male group showed higher indifference with 54.55% did not rate any rendering mode better than the other. Furthermore, while the total percentage of Male with a preference for Colored mode was lowered than that of Female, there was no rating for “Much better in Grayscale” in the Male group. Figure F5.1 presented this.



**Figure F5.1:** Overall Preference by Gender - Frequency in Percentage

A Mann Whitney U-test was conducted to compare the Overall Preference rating between Male and Female groups (see Table T5.4).

The results showed that the difference in Overall Preference rating between navigating in Male and Female groups was not statistically significant ( $U=100.50$ ,  $Z=-.178$ ).

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<b>Ranks</b>				
	Gender	N	Mean Rank	Sum of Ranks
Overall Preference	Male	11	15.86	174.50
	Female	19	15.29	290.50
	Total	30		

### Test Statistics<sup>a</sup>

	Colored_vs_ Grayscale
Mann-Whitney U	100.500
Wilcoxon W	290.500
Z	-.178
Asymp. Sig. (2-tailed)	.859
Exact Sig. [2*(1-tailed Sig.)]	.866 <sup>b</sup>

a. Grouping Variable:  
Gender\_Recoded

b. Not corrected for ties.

**Table T5.4:** Overall Preference by Gender - M. Whitney U-test

## 5.3 Qualitative Analysis

Qualitative analysis was performed by analyzing the comments provided by the test participants for post-task Color mode question, post-task Grayscale mode question, and Post-study question. These were questions 4, 8 and 10 in the Google Survey Form. These questions were in the form of open text fields and were not marked compulsory. 23 out of the 30 test participants provided comments; some gave comments for all three questions while others only responded to one or two of the three questions.

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### 5.3.1 Words Cloud

At first, a words cloud service was used to generate a visual representation of keywords that were most mentioned by the test participants. All commenting texts for the three questions were input into TagCrowd to generate a visual representative of keywords that appeared with high frequencies in the comments. Such visualization enabled quick identification of the repeated topics or keywords shared by the test participants. Figure F5.2 was the output of this exercise.



**Figure F5.2:** Qualitative analysis - Words cloud generated

### 5.3.2 Themes from Comments

Thematic analysis was performed and there were five themes emerged from the comment entries (see Appendix D):

1. Preference for or Liking of Colored environment
2. Preference for or Liking of Grayscale environment
3. No preference for or Indifference of Colored and Grayscale environment
4. Feedback on Task Complexity
5. Feedback that was not under the study of this research

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### **Preference for or Liking of Colored environment**

6 test participants, or one-third of those giving comments, liked it that the environment was “colorful”, “lively”, and “more enjoyable”. Some of these test participants mentioned that they found the Grayscale environment “dull”, “unclear to find [...] depth of room”, and “reminds me of some apocalyptic movies”.

### **Preference for or Liking of Grayscale environment**

A smaller number of test participants (3) found the arrows “more visible” in the Grayscale version. One of them commented that they found the arrows were “a little bit more difficult to see” in the Colored environment.

### **No preference for or Indifference of Colored and Grayscale environment**

4 test participants indicated that they did not find any difference between the two navigation tasks.

### **Feedback on task complexity**

A few test participants (5) mentioned that the navigation tasks were “simple” and “short”.

It was also noted that the Overall Preference rating varied for test participants with no comments and test participants gave feedback that the navigation tasks were simple and short. Some indicated a preference for Color mode while others opted for Grayscale mode.

### **Feedback not under the study of the research**

A high number of test participants (17) gave comments that were not under the study of this research. These comments, to different extents, were mainly about the difficulties and naturalness of the first-person character’s movements using mouse and arrow keys, the mouse sensitivity. Some of these comments also made reference to the WASD keys - a combination of W-A-S-D keys on a keyboard that is commonly used in a computer video game. The comments included phrases such as “slow mouse speed”, “cannot look up or down”, “too sensitive”.

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<b>Comment Theme</b>	<b>Number of comments</b>
Preference for Colored mode	6
Preference for Grayscale mode	3
Indifference between Colored & Grayscale mode	4
Feedback on Task Complexity	5
Feedback not under this study	17

**Table T5.5:** Comment themes & Number of comments received

In summary, the key observation from the qualitative analysis was that, there was a lot of feedback received that were not relevant to the study objective. Besides, for the test participants with relevant feedback, the majority showed a preference for the Colored environment, attributing to the colorfulness and liveliness of the environment. On the other end, comments with a preference for the Grayscale environment quoted the high visibility of the signage. However, since the feedback received was low in quantity and short in detail for this Qualitative analysis, a conclusion about the preference for Colored or Grayscale mode could not be firmly drawn upon.

## Discussion

With no significant difference statistically found for Time Taken, Easiness, and Enjoyability as documented in Chapter 5 Results, the null hypotheses cannot be rejected and accordingly the hypotheses H1 and H2 cannot be accepted. It cannot be concluded that rendering the camera feeds in Grayscale mode improves the Effectiveness nor reduces Users Satisfaction in navigation using a MAR.

One important aspect to consider while exploring the indifference results was the fact that the experiment conducted in the research was not the exact setup of a MAR application. The test participants performed the navigation task on a computer rather than a mobile phone. Instead of holding a mobile phone during the actual navigation task, the test participants were in front of their own computer performing the navigation tasks on the screen.

### **6.1 Possible Reasons for the Indifference**

#### **6.1.1 Field of View and Exploration Level**

Firstly, there are differences in the fields of view in navigating under an actual MAR setup and navigating under a computer setup like what was in the conducted experiment. With an actual MAR application, test participants have a wider field of view in the sense that their body movements or eye movements could potentially change the view they have on the surrounding environment, in this case, the actual navigation scene. On the other hand, test participants performing the navigation task on a computer have a relatively fixed field of view - the computer screen in front of them. Considering

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cover and over attention, testing with an actual MAR application brings opportunities for focus attention to be achieved through overt attention, in other words, with eye movements. On the other hand, testing on a computer screen likely placed the test participants' focus attention through covert attention. Furthermore, in terms of spatial knowledge, testing on a mobile AR application might involve more route knowledge where the navigator is in the real environment and build up the information about the navigation scene through a first-person perspective.

Accordingly, testing on a computer screen could mean a different level of exploration where a test participant's attention is directed to the computer screen area. That could possibly mean the test participants would explore the surrounding environment less while performing the navigating task as compared to when they navigate using MAR application. As a result, there was an insignificant difference found for the variables studied in the experiment, especially the Time Taken to complete navigation tasks.

### **6.1.2 Depth of View and Color Advantages**

Similarly, there are differences in depth of view for navigating in an actual MAR setup and navigating in a computer setup. In the former, test participants have the navigation aids (the arrows) layered on top of the navigation scene (the actual surroundings where the test participants are at). In the latter, the navigation aids are layered on top of the navigation scene background which is rendered in 3D and is viewed on a computer screen.

When tested with the MAR app setup, in Grayscale mode, the test participant may not have a good knowledge of the navigating scene captured by the phone camera due to the lack of salience and conspicuity in the absence of colors (Frey et al., 2008), as compared to testing in Colored mode. On the contrary, with testing on a computer screen, the test participants can always see what is in front of them (what is shown on the computer screen) in both Colored mode and Grayscale mode. The salience and conspicuity advantage of color takes less effect in testing on a computer screen and thus generates less variance in task performance, especially the Time Taken.

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### **6.1.3 Task Complexity**

Additionally, task complexity may also be one factor that leads to indifference results. As found in the Qualitative analysis, a number of test participants reported that the navigation tasks were short and simple. Likewise, the mean rating for Easiness is 4.47 and 4.40 for the Colored mode task and the Grayscale task respectively in the Quantitative analysis. That the navigation task given is short and simple could mean there was not enough time for the test participants to experience and feel the differences between the Colored mode and Grayscale mode. On the account of that, there was no significant difference in the ratings for Easiness and Enjoyability. Furthermore, the indifference result was also found gender-wise and that is in line with the suggestion from Coluccia and Louse (2004) that significant gender differences disappear in simple tasks.

## **6.2 Alternative View - No Difference**

Having different factors considered in the previous sections, there is, however, an alternative way to look at the indifference in the results - there might actually be no difference in MAR navigation between Colored mode and Grayscale mode. While the hypotheses proposed were not supported, the results might open up a new finding - that the camera rendering mode, in Colored or in Grayscale, might not actually matter in similar navigation tasks.

In the context of this study, the navigation task is a goal-oriented task. Possibly, when performing such a goal-oriented task, the navigator's focus is set on achieving the goal, in this case, to reach the target destination. The background rendering mode is then of less attention and less effect to the navigator's time performance as long as the navigation aids remain reasonably visible to support the navigation. This is discussed by Borji and Itti (2013) as top-down attention being task-driven. It also aligns with the selective attention model introduced by Milanese et al. (1994) which suggested that the visual scene is extracted and processed through reducing complexity.

Moreover, the indifference between males and females' performance is also in line with recent empirical studies related to gender performances in virtual environments by Dünser et al. (2012) and Munoz-Montoya et al. (2019).

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## **6.3 Restricted Qualitative Data**

Another important observation noted from the results is that a high number of the test participants gave feedback that was not directly under the study of this research. Many test participants with comments did not realize they were tested for Color/Grayscale preference and gave feedback on the character's movements and mouse sensitivity (section 5.3 Qualitative Analysis).

On one hand, that means the survey was finely designed in a way that it did not give hints to what was being tested which could possibly cause bias. On the other hand, though, it means the data collected for qualitative analysis is limited since the test participants did not know clearly what they were expected to give input on.

Additionally, the comments received in the responses are also short in length and simple. This is likely due to the fact that the comments were collected through an online survey where test participants have the tendency to provide brief responses or to skip giving responses altogether.

The mentioned disadvantages could be attributed to the absence of the researcher in moderating the experiment as well as administrating the open questions. Without the clarifications and follow up questions from the researcher in person, qualitative data collected is small in scale as a result.

## **6.4 Research Limitation**

### **Not Exact MAR Setup**

As discussed earlier, one key limitation of this research is the fact that the experiment was conducted on a computer screen instead of through an actual MAR application setup, given the mentioned schedule and circumstance. The difference in environment setups means findings from the study could only be partially drawn upon.

### **No Color Vision Deficiency Test**

Differed from the originally planned experiment, being an online survey with possible privacy concern from the voluntary test participants, the actually conducted test

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did not have the Color Vision Deficiency (CVD) test performed to screen the test participants for CVD. The research results thus are taken with an assumption that the test participants do not have CVD. Given that this study centers around color, this is a significant assumption to undertake.

## **Experiment Design**

First of all, the navigation tasks designed for the experiment are easy and short and that might have resulted in the indifference results. With a more complex task design, there might have been more findings registered.

Secondly, the experiment was conducted through an online survey form without the presence of the researcher for experiment administration. The test participants might not exactly follow the instructions and could cause inaccuracy in certain measurements. For example, in the example that was excluded as an outlier, the test participants commented that he or she spent a lot of time exploring the test environment in one task, which caused a high difference in time taken between the two tasks.

Besides, since the results are self-reported by the test participants, there could potentially be data entry errors, especially for the time taken data.

Furthermore, the test participants were recruited through the researcher's Facebook profile and the local International student group. Given such convenient sampling approach, the study results could be subject to selection bias.

There is also a technical mistake in the experiment design where the built-in first-person character movement has two moving speeds - walking speed and running speed, which can be activated by holding SHIFT key. The running speed module was overlooked and not disabled from the built-in. Accordingly, there were two test participants reporting lowered time taken using SHIFT. These two test participants results were not excluded from the data analysis because their time difference between Colored and Grayscale tasks do not fall in the outliers group. While the time taken results reported by the rest of the test participants do not suggest running speed was used, it is a limit of the experiment that the moving speed was not controlled and disabled for standardization.

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Lastly, the Grayscale mode used in the Experiment is the built-in Grayscale color grading feature of Unity. The exact conversion formula used to generate the Grayscale mode is not known for a more in-depth color study. The Grayscale rendering on screen is taken as-is.

## Conclusion

This research has sought to study if rendering the MAR camera feeds in Grayscale mode (as opposed to in Colored mode) has implications on the Effectiveness and User Satisfaction of navigation experience using MAR application.

While the results from the study statistically suggested no significant differences between Grayscale mode and Colored mode in terms of Time taken to complete task, Easiness to perform task and Enjoyability when performing navigation tasks, there was an alternative explanation for the indifference, and possibly a research finding in itself, that the camera feeds rendering mode might not matter in the context of navigation using MAR application.

The research sets the concept for design considerations in using MAR for navigation. If the Grayscale mode brings equivalent effectiveness and user satisfaction in the specific context of navigating using MAR, Grayscale mode could be utilized for less data transmission on mobile, where data volume matters. Furthermore, thanks to the high contrast and visibility that it offers, Grayscale mode could also benefit the color vision deficiency community with grayscale-based designs tailored to their needs.

For future study, conducting experiments on the actual MAR setup would be the reasonable next step in relation to this research. That provides more accurate replication of the navigation experience. Increasing navigation task complexity in the testing could also be done to potentially allow more findings. Beyond that, pertaining to navigation using MAR, researches could also be expanded to the design of the navigation aids, for example, the color of the arrows or the arrows placement position.

## Personal Learning Outcome

Through the course of this study, I have gained more knowledge about augmented reality, mobile augmented reality, and virtual environments in general. Navigation theory and concepts, visual attention, color information, and its effects are among other subject areas that I have built up.

In preparing for the study, I have read and learned more about different research quantitative and qualitative methods. Additionally, the different usability metrics for measuring user experiences are useful knowledge for my Interaction and User Experience design career path.

Furthermore, I have learned the how-to of planning and conducting a research, from research preparation, data collection to data analyzing, results presenting and discussing. With the unexpected change of the experiment approach mid-way, I also experienced and got hold of the advantages and disadvantages of conducting research online. Besides, with the experiment switching from mobile phone to computer screen, I also learned that conducting an experiment with not an exact setup of the original study subject could have immense impacts on the experiment results.

Finally, to prepare for the experiment, I was exposed to technologies and tools that I had not worked on earlier including Apple ARKit, Unity, 3D modelling and C# scripting.

In brief, it was an appreciable experience for me to work on this thesis, with joys acquiring new knowledge and picking up skillsets along the way.

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# Appendix

# A Google Survey Form

4/25/2020

Camera Feeds for MAR Navigation

## Camera Feeds for MAR Navigation

This experiment objective is to study a specific design aspect of mobile augmented reality application

\* Required

### Overview

This experiment needs to be performed on a computer (desktop or laptop) and is best supported on Chrome browser. It takes approximately 10-15 minutes to complete the experiment.

There are 4 sections in this experiment:

- Section 1: Demo Tutorial
- Section 2: Navigation Task 1 & Post-task Survey (4 questions)
- Section 3: Navigation Task 2 & Post-task Survey (4 questions)
- Section 4: Post-study Survey (6 questions)

### Data Collection & Confidentiality

No personal identifiable information will be collected or published as part of this study.

Since Google Form will be used to collect your responses, your IP address might be registered by Google form service provider as part of their setup. However, your IP address will not be recorded as part of this study and will not be used to identify you or your responses.

Data to be collected include your task performance results, your general demographic information and your responses to the study survey questions.

Data collected will be stored in my personal computer/laptop, Google Form and NTNU's computer where needed until the deletion date.

### Information Letter and Consent Form

Read in details the "Information Letter and Consent Form" here [http://folk.ntnu.no/lcnguyen/findpenguin/Information\\_Letter\\_and\\_Consent\\_Form.pdf](http://folk.ntnu.no/lcnguyen/findpenguin/Information_Letter_and_Consent_Form.pdf)

Contact information for queries about this study can also be found in the "Information Letter and Consent Form".

### 1. Consent \*

*Check all that apply.*

I agree to provide consent as documented in the "Information Letter and Consent Form" and agree to proceed with this experiment.

### Section 1 - Demo Tutorial

Estimated time taken: 1 minute  
This Demo Tutorial is to get you familiar with navigating/walking in the experiment environment.

Please click on the link below. A new window will be opened. Environment loading may take 30 - 45 seconds.  
<http://folk.ntnu.no/lcnguyen/findpenguin/DemoTutorial/index.html>

AFTER you have completed the demo, please RETURN to this survey window and continue.

[https://docs.google.com/forms/d/15Cz6TsKN7mF6JzcUPqAZ2\\_Nlj8y2hRunhSvOrwF-y0/edit](https://docs.google.com/forms/d/15Cz6TsKN7mF6JzcUPqAZ2_Nlj8y2hRunhSvOrwF-y0/edit)

1/5

2. I have completed the Demo Tutorial \*

Mark only one oval.

- Yes
- No

Section 2 - Navigation Task  
1

Navigation Task 1  
Estimated time taken: 1-2 minute

INSTRUCTION:  
Please click on the link below. A new window will be opened.  
<http://folk.ntnu.no/lcnguyen/findpenguin/Task1/index.html>

NOTE DOWN the time taken at the end of your task.  
AFTER you have completed the task, please RETURN to this survey window and continue.

Fill in Time taken (in seconds) using format: [0-9][0-9].[0-9][0-9].  
For example: 45.23

3. Q1/ Time taken to complete Navigation Task 1 (in seconds) \*

Section 2 (cont.) - Post-task 1 Survey

Please indicate your evaluation of the navigation experience.

4. Q2/ Overall, I find the navigation experience in Task 1 EASY TO PERFORM \*

Mark only one oval.

- |                   |                       |                       |                       |                       |                       |                |
|-------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|----------------|
|                   | 1                     | 2                     | 3                     | 4                     | 5                     |                |
| Strongly Disagree | <input type="radio"/> | Strongly Agree |

5. Q3/ Overall, I find the navigation experience in Task 1 ENJOYABLE \*

Mark only one oval.

- |                   |                       |                       |                       |                       |                       |                |
|-------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|----------------|
|                   | 1                     | 2                     | 3                     | 4                     | 5                     |                |
| Strongly Disagree | <input type="radio"/> | Strongly Agree |

6. Q4/ Any comments you would like to share about the navigation experience

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Section 3 - Navigation Task 2

Navigation Task 2  
Estimated time taken: 1-2 minute

INSTRUCTION:  
Please click on the link below. A new window will be opened.  
<http://folk.ntnu.no/lcnguyen/findpenguin/Task2/index.html>

NOTE DOWN the time taken at the end of your task.  
AFTER you have completed the task, please RETURN to this survey window and continue.

Fill in Time taken (in seconds) using format: [0-9][0-9].[0-9][0-9].  
For example: 45.23

7. Q5/ Time taken to complete Navigation Task 2 (in seconds) \*

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Section 3 (cont.) - Post-task 2 Survey

Please indicate your evaluation of the navigation experience.

8. Q6/ Overall, I find the navigation experience in Task 2 EASY TO PERFORM \*

Mark only one oval.

1    2    3    4    5

---

Strongly Disagree                  Strongly Agree

9. Q7/ Overall, I find the navigation experience in Task 2 ENJOYABLE \*

Mark only one oval.

1    2    3    4    5

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Strongly Disagree                  Strongly Agree

10. Q8/ Any comments you would like to share about the navigation experience

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Section 4 - Post-study Survey

About the Experiment

11. Q9/ Overall, I think the navigation experience is \*

Mark only one oval per row.

	Much better in Task 1	Slightly better in Task 1	Neither one is better	Slightly better in Task 2	Much better in Task 2
(select one)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

12. Q10/ Any additional comments you might have

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Demographics

13. Q11/ Your Age \*

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14. Q12/ Your Gender \*

Mark only one oval.

- Female
- Male
- Prefer not to say

15. Q13/ Have you ever navigated in similar virtual environment (e.g. playing computer game) \*

Mark only one oval.

- Yes
- No

16. Q14/ Prior to this experiment, how familiar are you with navigating in similar virtual environment \*

Mark only one oval.

	1	2	3	4	5	
Not familiar at all	<input type="radio"/>	Very familiar				

This content is neither created nor endorsed by Google.



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## B Letter of Information and Consent Form

### INFORMATION LETTER & CONSENT FORM

#### About this project

This “Camera Feeds for Mobile Augmented Reality Navigation” project is part of my master thesis in the Master of Interaction Design program. The project objective is to study a specific design aspect of mobile augmented reality application.

#### Responsible for this project

I, Le Chuong Ngu Nguyen, is the student responsible for this project.  
My research supervisor: Ole E. Wattne.

#### Test participants

Test participants recruited are people in the age range of 18 to 40 who are familiar with technologies.

#### Your involvement in this study

If you decide to participate in this study, you will take part in the following activities:

1. Perform navigation tasks in mobile augmented reality environment and/or in a virtually simulated environment.
2. Provide general demographic information about yourself such as age, gender, etc...
3. Provide experiment evaluation feedback through survey questions.

#### Voluntary participation

Participation in this project is voluntary. At any time, you can choose to withdraw from the study without having to state a reason.

#### Data collection and processing

No personal identifiable information will be collected or published as part of this study.

Since Google Form will be used to collect your responses including task performance, your IP address might be registered by Google form service provider as part of their setup. However, your IP address will not be recorded as part of this study and will not be used to identify you or your responses.

Data to be collected include your task performance results, your general demographic information and your responses to the study survey questions.

Data collected will be stored in my personal computer/laptop, Google Form and NTNU computer where needed until the data deletion date.

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**Your personal data at the end of this project**

This project is planned to end in 30th June 2020. Additional time contingency is reserved for unforeseen circumstances that may impact the project progress; this project study data is planned to be deleted after 15<sup>th</sup> August 2020.

**Your rights**

So long as you can be identified in the collected data, you have the right to:

- Access the personal data that is being processed about you.
- Request that your personal data to be deleted.
- Request that incorrect personal data about you is corrected and/or rectified.
- Receive a copy of your personal data.
- Send a complaint to the Data Protection Officer or The Norwegian Data Protection Authority regarding the processing of your personal data.

**To find out more**

If you have queries about the project or your data, please contact:

- Ole E. Wattne (Main Supervisor): ole.wattne@ntnu.no, 61135448
- Le Chuong Ngu Nguyen (the researcher): lcnguyen@stud.ntnu.no.
- Our Data Protection Officer: Thomas Helgesen, thomas.helgesen@ntnu.no, (+47) 93079038.

Sincerely yours,  
Le Chuong Ngu Nguyen

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**Consent**

I have received and understood information about the project "Camera Feeds for Mobile Augmented Reality Navigation" and have been given the opportunity to ask questions. I give consent to participate in the study. I give consent for my personal data to be processed until the planned data deletion date, which is currently planned on 15<sup>th</sup> August 2020.

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(Signed by participant, date)

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## C Experiment Footage Video & 3D Models Sources

### Experiment Video

[Link](#) to the video footage of the experiment task.

### 3D Models Sources

3D Model	Made Available at
Penguin	<a href="#">Unity Asset Store</a>
Snap Office set	<a href="#">Unity Asset Store</a>
Picture Frame	<a href="#">Unity Asset Store</a>
Sofa	<a href="#">TurboSquid</a>
Reception Desk	<a href="#">TurboSquid</a>
Indoor Plant 1	<a href="#">TurboSquid</a>
Pool Table	<a href="#">TurboSquid</a>
Kitchen Bench & Chairs	<a href="#">CGTrader</a>
Indoor Plants Set	<a href="#">CGTrader</a>
Vending Machine	<a href="#">CGTrader</a>
Meeting Room Table	<a href="#">CGTrader</a>
Arrows	<a href="#">Clara</a>

**Table T8.1:** 3D Models Sources

## D Qualitative Analysis - Comment Themes

No.	Comments_Colored_Post-task	Comments_Grayscale_Post-task	Comments_Post-study	Comment Theme				
				Prefer Color	Prefer Grayscale	No Difference	Task Complexity	Not Relevant Feedback
1		Easier to navigate compared to Task 1	Would be helpful if there are signs/labels (e.g. room 1, room 2)		<input checked="" type="checkbox"/>			
2	There's no feedback when I hit the wall	I don't have esc on mac						<input checked="" type="checkbox"/>
3			Will you do the experiment under the more complicated scene?				<input checked="" type="checkbox"/>	
4	The footstep is a bit scary		Didn't feel so much difference in those two experiences			<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>
5	I couldn't turn around.							<input checked="" type="checkbox"/>
6	I cannot look up and down, only left/right, which makes me feel dizzy							<input checked="" type="checkbox"/>
7	It was pretty good and enjoyable. Navigation arrows were clear and enjoyable.	The navigation experience was a bit less enjoyable as it did not have any colours except for the arrows. Due to that, it was bit unclear to find the the end of the wall and depths of room.		<input checked="" type="checkbox"/>				
8	It was fairly simple. Just like game controls.	I noticed that all the objects except the arrows were grey. So the guiding arrows were totally in focus. But it felt sort of dull as compared to the last task where it felt like i am in a virtual but		<input checked="" type="checkbox"/>			<input checked="" type="checkbox"/>	
9	Unable to look up to the ceiling or down to the floor	I like the colourful version		<input checked="" type="checkbox"/>				<input checked="" type="checkbox"/>

No.	Comments_Colored_Post-task	Comments_Grayscale_Post-task	Comments_Post-study	Comment Theme				
				Prefer Color	Prefer Grayscale	No Difference	Task Complexity	Not Relevant Feedback
10		i liked better black and white, the arrows much more visible	as i was not using a mouse, I struggled a bit with turning the "view" where i needed		<input checked="" type="checkbox"/>			<input checked="" type="checkbox"/>
11	I didn't really follow the navigation, because I am curious about the whole environment, so I did explore around each rooms	I forget to mention that I am not so good at doing these kind of "game"; this time I am following the arrow, but I only use a touch panel, so it might not as good as using a mouse.	I did not realize what's the difference between the first one and the second one.			<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>
12	Same here: the sensitivity of movement that happens when I use the arrow keys and the mouse to navigate around was not as smooth as I could have wished for	the sensitivity of movement that happens when I use the arrow keys and the mouse to navigate around was not as smooth as I could have wished	Possible arrow keys and mouse are too sensitive					<input checked="" type="checkbox"/>
13	I think I was quicker this time because I pressed shift right away. The arrows were a little more difficult to see compared to the grayscale version, but still easy enough	It was fun and intuitive. My gaming experience made me hold shift while navigating, which made me move quicker. I did feel a bit of competitive spirit, so I did not take my time to look at the environment			<input checked="" type="checkbox"/>			<input checked="" type="checkbox"/>
14		I can walk though the table. It's funny						<input checked="" type="checkbox"/>
15	I noticed more colourful background, and this time I follow the arrow that makes me found the penguin quicker.	Felt mild dizziness with the navigation, especially during turning		<input checked="" type="checkbox"/>				<input checked="" type="checkbox"/>

No.	Comments_Colored_Post-task	Comments_Grayscale_Post-task	Comments_Post-study	Comment Theme				
				Prefer Color	Prefer Grayscale	No Difference	Task Complexity	Not Relevant Feedback
16	Didn't understand the difference between Task 1 and 2.		Initially color didn't matter much, which i didn't realize for the fact that the task was short. Could be because some games I play are in b/w. Functionality wise it was similar			<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
17			Unfortunately I did not pay much attention to the navigation experience, not enough to notice any change. I was just following the arrows.			<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
18	Same as the last comment	Slightly difficult to simultaneously move and look around on a laptop with no external mouse	My laptop is quite old so there was some initial lag while playing the game. May have affected the timer slightly.					<input checked="" type="checkbox"/>
19	Program have little bit slow feedback, hard to move around.							<input checked="" type="checkbox"/>
20	Maybe a bit slow mouse speed to navigate around	Used to navigate with WASD in these kind of environments						<input checked="" type="checkbox"/>
21		I felt that having to use my left hand for looking and right hand to walk was a bit unatrual. Might be just me, but i feel it should be the other way around, and use the wasd keys to walk and right ha						<input checked="" type="checkbox"/>

No.	Comments_Colored_Post-task	Comments_Grayscale_Post-task	Comments_Post-study	Comment Theme				
				Prefer Color	Prefer Grayscale	No Difference	Task Complexity	Not Relevant Feedback
22	I think the addition of furniture helped with the navigation and made is more enjoyable as compared to the first task.	It is fairly intuitive.	Task 2 was better than task 1.					
23	Easier than the first time, mainly cause I gained more experience, I suppose? At first I rate the enjoyability of this 2nd round same like the 1st time, but then again the 2nd time around the environment is actually colored, so I do find it more lively, compared to the 1st time where everything is so ashy aside from the yellow arrow it reminds me of some apocalyptic movie	It's a bit hard to say much considering it was a relatively simple task. But overall it does manage to make me feel like a real walking experience, in the sense that I did not use any key aside from the "Up" arrow, all the while positioning myself in the environment using only the mouse. It feels like in real life, my legs always only move forward while my head will coordinate the whole body to change its direction.		<input checked="" type="checkbox"/>			<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
24	I feel like I'm getting more of a hang of it now. With practice I think the experience improves.	The navigation instructions are easy in themselves, but because they are different from the navigation options I'm used to from other games etc. (not a combination of arrows and mouse) it feels a bit unnatural and I don't move around as fast as I think I would if I just used the arrows.	I have some experience playing computer games, but mostly 2D platform games and most intensely as a child. As an adult I don't really play any games or do any activity on the computer that involves this kind of navigation. I missed being able to look up and down.					<input checked="" type="checkbox"/>

