Explorative study
towards supporting dredgers' control work by HoloLens

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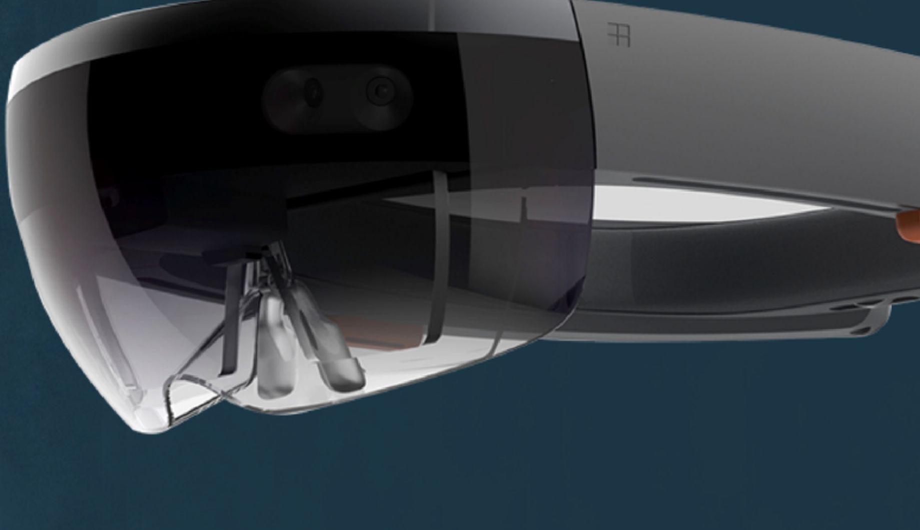

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Preface

The graduation thesis is the final deliverable of the Master graduation program Design for interaction. It is also the final outcome of my long journey for exploring supporting novice operators' dredge control work by HoloLens for Royal IHC.

The project is more difficult than I originally assumed. It is such a tough work that I could not finish it without other people's help. I am now expressing my gratitude to everyone who help me and give me support through the whole project.

First of all, I would like to thank my supervisor team a lot. My chair Imre Hovath and my mentor Doris Aschenbrenner really teach me so much. They give me professional support in their research field. They also teach me about writing, planning and logic thinking. What is more? Their constant encouragement and motivation keep pushing me go ahead toward my goal. It is a great honor to have them as my supervisor team.

Secondly, I am grateful to Jan-Theun van de Have, my company mentor from Royal IHC. He is always energetic and gives me all the support he can provide. Although busy with daily work, he still spares time for me. Without his help, I cannot even find any interviewees and start my research. Meanwhile, I shall specially thank Ewin Peters, who is the Unity developer. I could not make the prototypes work without him.

Thirdly, I would like to thank all my friends that give me suggestions and participant in my user test. Their help is of great importance otherwise I could not finish my project.

Last but not the least, I would not forget my parents, my friends in China. Their encouragement, accompany and support are important to me. Because of your existence, I could always chair up and overcome all the challenges I have met.

Executive Summary

The worldwide company named Royal IHC proposed this graduation project. Royal IHC is a reliable supplier of innovative and efficient equipment, vessels and services for the offshore, dredging and wet mining markets. Trailing suction hopper dredger (TSHD) is one of the company's main products for port maintenance, especially in confined space. The Beagle is one kind of TSHDs that Royal IHC offers. A dredge operator is doing all the dredge control task in the dredge operator cockpit.

The human-machine interface (HMI) of the dredge operator cockpit is developed on a perpetual basis. In the process of development, new characteristics, new symbols or buttons have been added to the already existing lectern. However, it has become complicated to use these new interfaces when a significant amount of information is available. This concomitant complexity makes it difficult for inexperienced operators to quickly find the information needed and to keep control over all pieces of information. Therefore, they need to spend longer time in training in order to be fully efficient.

The latest interface technology augmented reality has attracted attention. Royal IHC is interested in head-mounted devices, especially HoloLens. Royal IHC sees the potential of HoloLens in terms of supporting the control tasks of dredge operators, but this assumption still needs to be proven by operational research. Therefore, the essence of this project is an explorative study, which is targeted to discover if there are possibilities of HoloLens to support dredge control work of novice operators. The company is interested in knowing if what and how novice dredge operators can benefit from using HoloLens and will decide if they will be going to do more research in this domain.

The project starts with technology research about augmented reality and the device HoloLens. The research of augmented reality contains its technology, its application and benefits. The research of HoloLens involves the ability of the device, the comparison with other similar devices and its unique applications and benefits. The research of technology helps me understand augmented reality and HoloLens, which gives more inspiration for the later conceptualization.

Then, there is user research to understand novice operators working environment, their tasks and their problems. It is hard to contact with real novice operators. For this project, experienced operators are interviewed instead. Their operation in a simulated cockpit is observed. The company document of the tasks and software is studied. According to the research, a task table is generated. Two personas of the novice operator are created. The problems they may have are analyzed according to the interview and observation about the operation habit.

The conceptualization about how HoloLens could support dredger's control work starts based on the task table. Because augmented reality could give more help in spatial navigation, the tasks of placing suction tubes onto the ground are selected. Combining the research of technology and user research, three different concepts are generated. The concepts give

different levels of support. The core of the concepts is to only give the essential information in front of the novice operator's eyes so that the novice operator does not need to switch attention between screens and the window. The concepts are compared with their strengths and weaknesses. There is a big difference between the concepts, which is the perspective. The information is provided by a first person's perspective and a third person's perspective. It is still not sure which perspective could give better user experience and results in better performance. Thus, it is decided to have two prototypes with the two perspectives.

A user test is conducted with two groups of people. One is Royal employees who have basic dredge knowledge, which can be seen as novice operators. The other is students from industrial design faculty. Both groups are divided into two subgroups then — one tests with the first person's perspective. The user test with Royal IHC is aimed to find out if novice operators can benefit from HoloLens and what benefit they can have compared with the current system. The user test with students is aimed to find out which perspective can give better user experience and results in better performance. The usability, workload and situation awareness are measured during the tests.

All the qualitative and quantitative data collected from the user test are studied. It is found that: Compared with the current system, HoloLens applications can give the information in a more straightforward way. Compared with the current system, simplified signals with its spatial property in HoloLens applications are easier to understand. Thus, compared with the current system, HoloLens applications require less workload. With the third person's perspective, operators could have a more transparent overview of the situation than with the first person's perspective. It is more easier for novice operators to learn the use of HoloLens applications than people without any dredge knowledge.

It is worth to research deeper about How HoloLens could support other dredge control tasks. It is also suggested to have more tests with IHC employees or real operators. Meanwhile, the development of HoloLens should be paid attention to as well. All in all, HoloLens have great potential to support novice operators' dredge control work and even change the way of control.

TABLE OF CONTENT

1. Introduction

The purpose of this chapter is to provide an overview of the context of the project. The assignment and problem definition are analyzed in order to find research questions and define the research field.

1.1. Background and context

1.1.1. Trailing suction hopper dredger

The trailing suction hopper dredge (TSHD) is a versatile vessel that unites dredging transport and discharge in a single piece of equipment. TSHDs are self-propelled, sea-going vessels with a traditional hull space. TSHDs can easily handle soft and loose soils, such as sand, silt and gravel and have a wide range of applications, including the deepening and maintenance of waterways, land reclamation and port construction, mining and the supply of marine aggregates.

1.1.2. Dredge control work

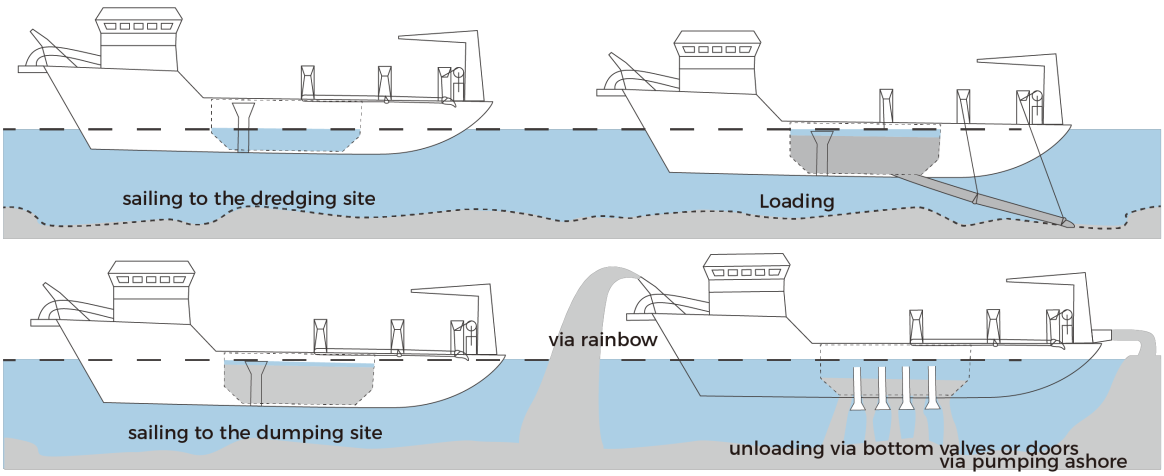


Figure 1: Dredge cycle contains 4 phases

The entire dredging process is a continuous cycle of 4 main activities (Figure 1): sailing to the dredging site, loading, sailing to the dumping area, and unloading.

For loading and unloading, a lot of different dredge equipment like gantries, winches, dredge pump and so on (Figure 2) need to be controlled. Dredging control is a really complicated process.

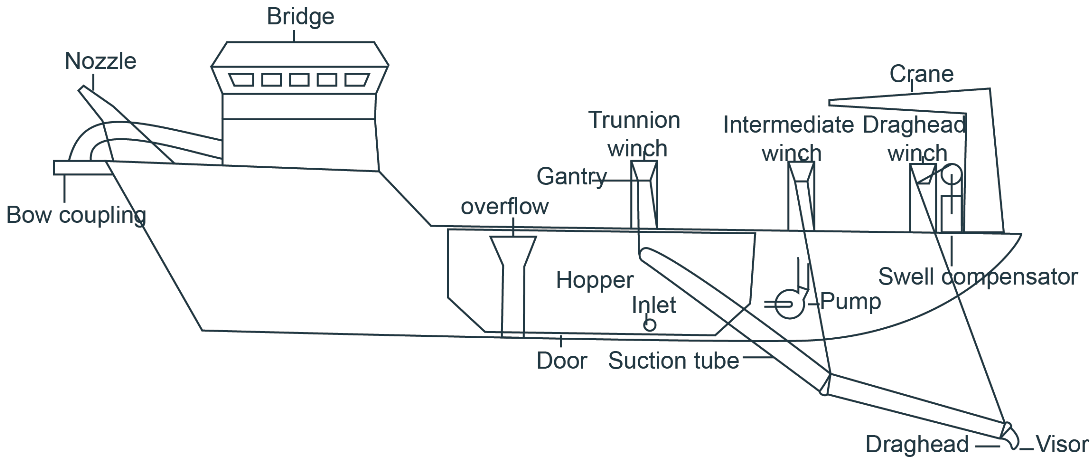


Figure 2: Structure and dredge equipment of TSHD

The dredging process is very complex. There is a dredge operator especially doing all the dredge control tasks on TSHD.

The dredge operators perform dredge control tasks via the dredge operator cockpit in the bridge of the vessel. The dredge control cockpit involves software and hardware. The software and hardware are called Human Machine Interface (HMI).

1.1.3. Royal IHC and IHC Systems

Royal IHC is focused on the continuous development of design and construction activities for the specialist maritime sector. It is the global market leader for efficient dredging and mining vessels and equipment with vast experience accumulated over decades. It is a reliable supplier of innovative ships and supplies for offshore construction.

IHC Systems is one of the business units of the Royal IHC Company. IHC Systems is responsible for the development, production and simulation of the systems and instrumentation of the vessels. These systems for controlling and simulating the vessels are delivered to their customers worldwide. IHC Systems continuously works to improve and automate their systems in order to optimize the dredging process.

Thus, IHC Systems is trying their best to develop the most efficient HMI of the dredge operator cockpit. New functions are contiguously invented and added into the HMI.

1.1.4. Challenge

(1) (2) (3)

Figure 3: The evolution of HMI of dredge operator cockpit: (1) Dredge operator cockpit in 1990s (2) Dredge operator cockpit in 2000s (3) Dredge operator cockpit nowadays

With the development of new technology like touch screens, the HMI of dredge operator cockpit looks less complex nowadays (Figure 3).

The HMI of the dredge operator cockpit is developed on a perpetual basis. In the process of development, new characteristics, new symbols or buttons have been added to the already existing lectern. However, it has become complicated to use these new interfaces when a significant amount of information is available, and it is not logically structure (Holwerda, 2016). This complexity makes it difficult for unexperienced operators to quickly find the information they need and to keep control over all pieces of information. As a result, the overview of the total dredging process is decreased and novice operators are typically not able to complete the control tasks efficiently. Therefore, they need to spend longer time in training in order to be fully efficient.

1.2. Project

1.2.1. Assumption

Since the software engineers of IHC Systems are working on the existing HMI for years, the company wants to discover new perspectives and new technologies to help the dredge operators. The latest interface technology called Augmented Reality has attracted attention. The company is interested in head-mounted devices, especially Microsoft HoloLens. IHC Systems sees the potential of HoloLens supporting dredge control tasks for novice operators. They assume that with the support of HoloLens, it would take less time for a novice operator to learn to work as efficient as an experienced operator. But this assumption still needs to be proven by operational research.

1.2.2. Project definition and scope

The project is an explorative study. The project is targeted to discover if there are possibilities of HoloLens to support dredge control work for novice operators. IHC Systems is interested in knowing if, what, and how novice dredge operators can benefit from using

HoloLens. Based on the projects' results they will decide if they will be going to do more research in this domain.

The scope of the project is a dredge control cockpit of Beagle 8. Beagle 8 has the most advanced dredge control cockpit. And since Beagle 8 has two suction tubes, the HMI of its dredge operator cockpit is more complex than the HMI of vessels with one tube.

1.3. Research questions and approach

The main research question and specific sub-research question are the following:

- What are the most relevant HoloLens functionalities for this scenario?
  - What are the problems for novice operators duringtheir dredge control work?
  - What kind of support do novice operators need?
  - Which specific support functionalities can be provided on the AR HMD HoloLens?
- How can HoloLens be embedded into the whole working procedure?

In order to answer the research questions, the project is conducted with a specific approach consisting of technology overview, user research, conceptualization and concept evaluation.

The first step is to study the technology of Augmented Reality and HoloLens. The study is aimed to understand the technology with regards to the ability, the benefit, the application and the limitation.

As a second step, user research is carried out in order to understand the novice operator, their working environment, their tasks and their problems. The goal is to identify the set of tasks which are most problematic for novice operators. The specific problems of the tasks are analyzed accordingly.

Third, the identified tasks are further refined so that those where Augmented Reality could provide sufficient benefit are selected for further conceptualization. 3 different concepts are generated. After evaluation, one concept with 2 different perspectives are selected. Two prototypes are developed. I did all the design of the interface and interaction. The programming was done together with colleagues in Royal IHC Systems.

Finally, a user test has be conducted in order to test the performance of the different prototypes. The user test is aimed to find out whether the concept is better than the current system towards task performance and user experience. Meanwhile, it is also studied with which perspective's view, the novice operator could have better performance and user experience.

2. Technology overview

The objective of this section is to understand the technology, the ability, the limitation, and a variety of possible applications of Augmented Reality and the Microsoft HoloLens. Figure 5 shows an overview of the content of this chapter.

There are different definitions of augmented reality. Here is a universally accepted one from Azuma (1997):

- Combine real and virtual objects in a real environment
- Registers(aligns) real and virtual objects with each other, and
- Runs interactively, in three dimensions, and in real time.

Milgram (1995) created a reality-virtual continuum (Figure 4). The continuum explains the relationship of Virtuality, Augmented Virtuality, Augmented Reality, Mixed reality and Reality.

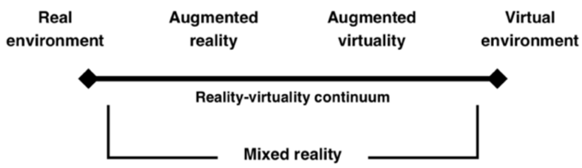


Figure 4: Paul Milgram's reality-virtual continuum

Microsoft HoloLens is the first self-contained, holographic computer, enabling users to engage with digital content and interact with holograms in the world. HoloLens provide a new mixed reality experience (Microsoft HoloLens). This claim is "not fundamentally false, but it leads to confusion as MR is thus often misunderstood as 'AR with real world understanding and anchoring'" (Coppens, 2017, pp. 39). As Milgram's reality-virtual continuum (1995), MR is a superset of AR, therefore neither a subset nor something different from AR. In fact, the HoloLens is an AR device and HoloLens applications are AR experiences (Coppens, 2017). The technology of AR would be researched as well.

The first AR system was made by computer graphic pioneer Ivan Sutherland (1968) and his students in 1960s. Although technology has developed fast since then, the key components needed to build an AR system are the same: displays, tracking system, the user interface and interaction technology. This is why this section is structured accordingly and includes the subsections display, tracking system, interface and interaction technology, application and limitations.

As this research focusses specifically on the device Microsoft HoloLens specific sections concerning the hardware, function features, extra input devices, development, limitations, comparison with similar devices, and application

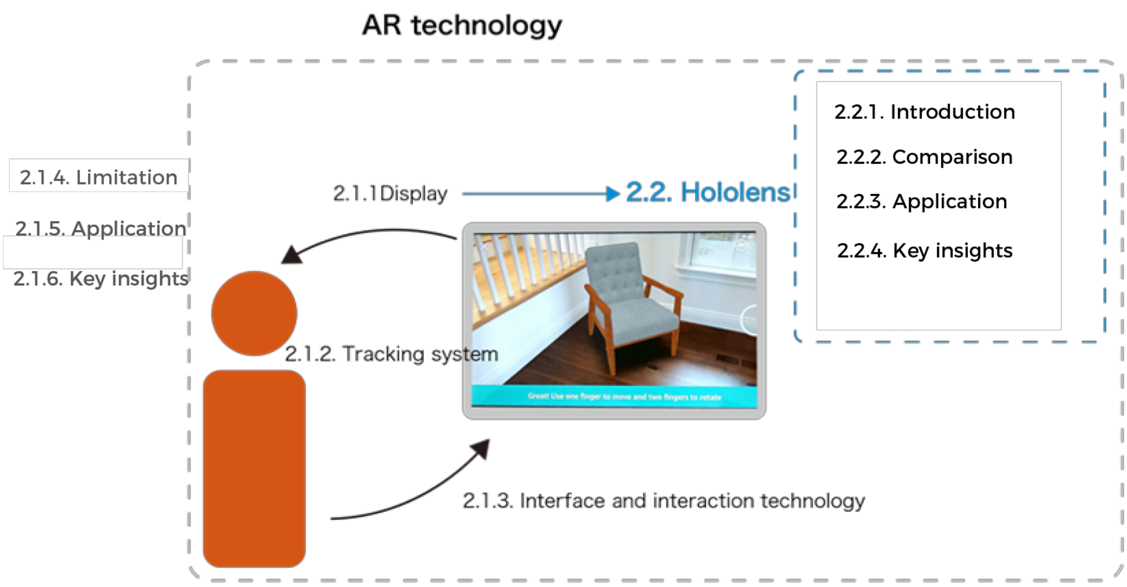


Figure 5: All the content of technology overview

The first AR system was made by computer graphic pioneer Ivan Sutherland (1968) and his students in 1960s. Although technology has developed fast since then, the key components needed to build an AR system are the same: displays, tracking system, the user interface and interaction technology. This is why this section is structured accordingly and includes the subsections display, tracking system, interface and interaction technology, application and limitations.

2.1. Augmented reality

2.1.1. Display

As shown in Figure 6, displays can be classified into 3 categories according to their position between the viewer and the real environment: Head-mounted display, hand-held display and spatial display (Bimber & Raskar, 2006). According to Bimber and Raskar (2006), spatial display refers to cases that the user viewpoints relative to the AR overlay is fixed. And those different kinds of display can be achieved by different devices:

- Head-mounted device: Google glass, HoloLens
- Hand-held device: smartphone, tablet,
- Spatial display: head-up display like AR display for cars

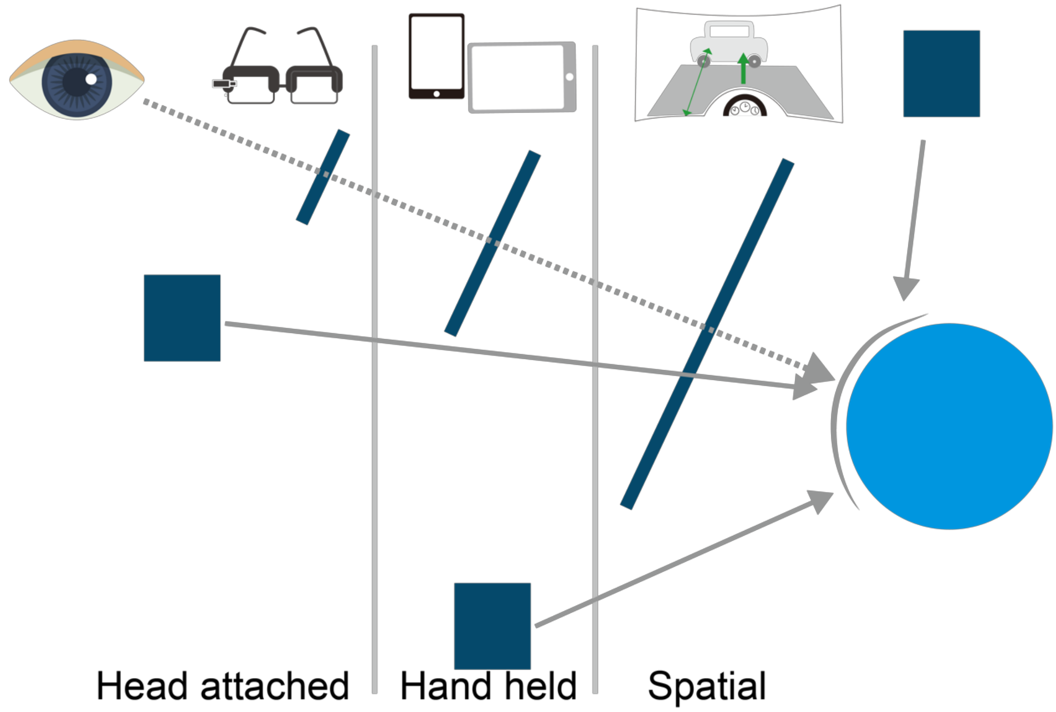


Figure 6: Visual display technique and position adapted from Bimber & Raskar (2006)

2.1.2. Tracking system

The tracking process in an AR system includes determining the position and orientation of the user in 6 degrees of freedom. Figure 7 shows a general overview of the tracking method used for AR systems. At first, tracking systems can optimized for outdoor or indoor usage. In both environments, either an external tracking system or an internal tracking system can be used.

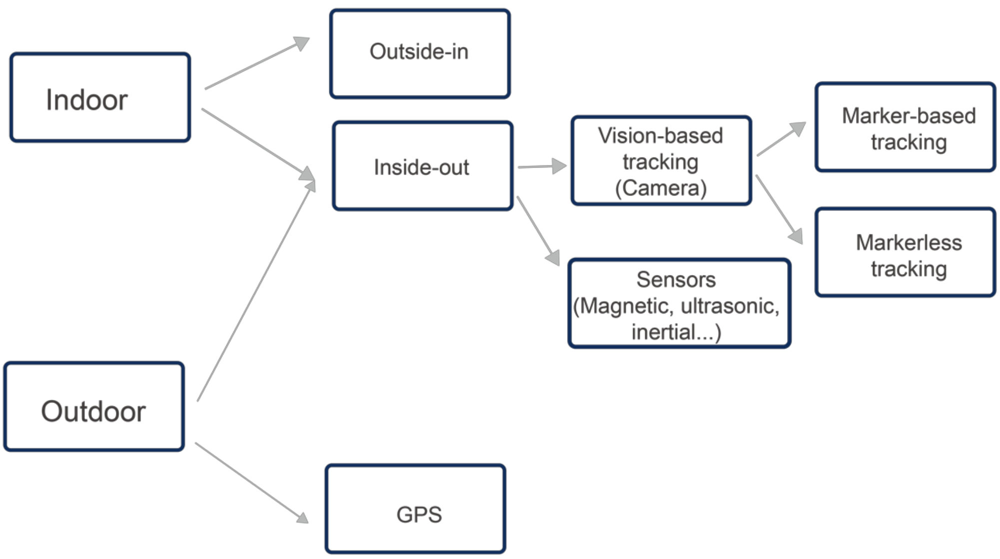


Figure 7: An overview of tracking methods in AR system adapted from Bostanci et al. (2013)

For indoor environment, the tracking methods can be classified into outside-in system and inside-out system. The outside-in system means the sensor equipment is installed in a fixed place in the environment. The tracked device contains some kind of markers, which can be identified by the fixed sensor equipment. There are active markers and passive markers. Active markers emit a signal (e.g. magnetic, light) which can be sensed by the sensor. Passive markers can be a pattern which can be easily isolated from the surrounding. (e.g. QR codes).

In the case of inside-out system, the user carries the sensor and the sensor tried to detect features or markers which are fixed in the surrounding environment. The sensor used here can be magnetic, ultrasonic, radio frequency identification sensors, inertial sensors or a camera (Bostanci, 2013). The camera results in the vision-based tracking, which involves marker-based tracking (Kato & Billinghurst, 1999) to marker-less tracking. Marker-less tracking includes natural feature tracking and 3D- structure tracking (Lepetit & Monocular, 2005).

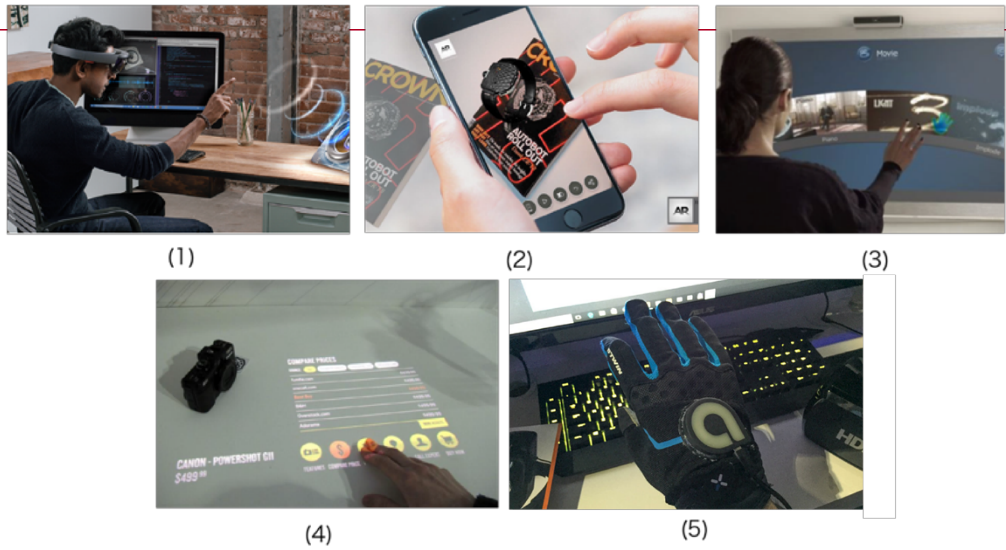
For outdoor environment, Global positioning system(GPS) is a good tracking option for instance, American 24-satellite Navstar GPS (Getting et al.,1993). Or the same as the inside-out system for indoor environment, inertial sensors (Corke et al., 2007) or cameras carried by the user can be used. Translational motion is tracked by accelerometers and rotational motion is tracked by gyros. The natural landmark in the outside environment can be recognized through the camera with vision-based tracking method.

Nowadays, hybrid tracking algorithms, which combine different tracking mechanisms, are the most promising way to deal with the difficulties posed by general indoor and outdoor mobile AR environment (H¨ollerer &Feiner, 2004).2.1.3. User interface and interaction technology

2.1.3. User interface and interaction technology

For AR environment, new interactive method and user interface (UI) are required to let users interact with both physical and virtual world (Harper et al., 2008). Those new UI paradigms can be visual UI, gesture recognition, haptic UI, gaze tracking, aural UI and speech recognition.

Visual UI and gesture recognition are mostly widely used for head-mounted device, hand-held device, head-up display and projective AR (Figure 8). A pair of VR gloves which can give additional haptic feedback of touching can be seen as haptic user interface and provide haptic feedback (Figure 8). For head-mounted device, visual UI and gesture recognition usually work together with gaze tracking.



[1]Figure 8: An overview of tracking methods in AR system adapted from Bostanci et al. (2013) (1) visual UI and gesture recognition of head-mounted device (2) visual UI of hand-held device (3) visual UI and gesture recognition of head-up display (4) visual UI and gesture recognition of projective AR (5) GloveOne haptic gloves enable touch feedback and weight sentation

For different AR systems, use multimodal UI paradigm, combining different interaction methods may provide users with a more intuitive experience.

There is another interesting UI technology which is towards human-machine symbiosis. Biometric devices can measure heart-rate and bioelectric signals which indicate human emotion. Current UI technology can utilize these data to create wearable sensor clothe (Farringdon et al., 1999).

2.1.4. Limitation of the technology

The currently available AR technology still has a lot of problems, like a limited field of view, limited processing power, the storage and so on. Despite the limitation of hardware development, the most critical limitation now for the AR technology are social acceptance issues. People are aware of the discomfort to others while interacting with AR. Carmigniani et al. (2010) mention, that AR devices need to be "subtle, discrete and unobtrusive as well as fashionably" to increase social acceptance.

2.1.5. AR application

Nowadays, AR has already been demonstrated to be beneficial in many different domains: training, manufacturing, inspection and maintenance, architecture and construction. A literature review finds AR application via HMD in product design (Klinker et al.,

[1] Image source: (1)www.microsoft.com(2)www.highend.media (3) https://www.pantechsolutions.net(4) https://phys.org (5) https://www.fudzilla.com

2002)(Webel et al., 1996), assembly task (Caudell and Mizell, 1992)(Tang et al., 2003), order picking (Feiner er al., 1993)(Reif & Günthner, 2009), inspection and maintance (Henderson & Feiner , 2009)(Webel et al., 2013)(Kim et al., 2018)(Dey et al., 2018). The research finds that, AR can be used to provide task related information with its spatial property, so that the user does not have to mentally transform information. Thus, the user can complete the task with less errors, less mental workload and higher accuracy (Tang et al., 2002). Meanwhile, the overlaid information should be carefully designed, for example with visual cue and hints, as suggested by (Welbel et al. 2011).

2.1.6. Key insights

To develop AR application, social environment should be researched as well. AR can provide information with its spatial property for the user. The user can understand their environment much more easily and quickly. The performance is improved with less error and the mental work load is reduced because of no need for mental transformation.

2.2 HoloLens

2.2.1. Introduction of HoloLens

[2]Figure 9: A user interacts with hologram by Microsoft HoloLens, 2016

HoloLens is head-mounted display connected with an adjustable inner headband (Figure 9). The headband can adjust HoloLens up and down, as well as forward and backward (Davies & Chris, 2015). The whole headset weight 579g.

[2] Image Source: https://www.microsoft.com

HoloLens possess an HPU, (holographic processing unit) a CPU and a GPU for processing data. The HPU is a coprocessor dedicated to integrating the real world and virtually generated content. The GPU is used to manipulate graphics and image processing. It consolidates and processes all the data from various sensors and produces a thin stream of useful information to the other processors (Wikipedia: Microsoft HoloLens). The see-through holographic lens is made with three layers of glass. A light engine is mounted above the displays and projects light on the lenses.

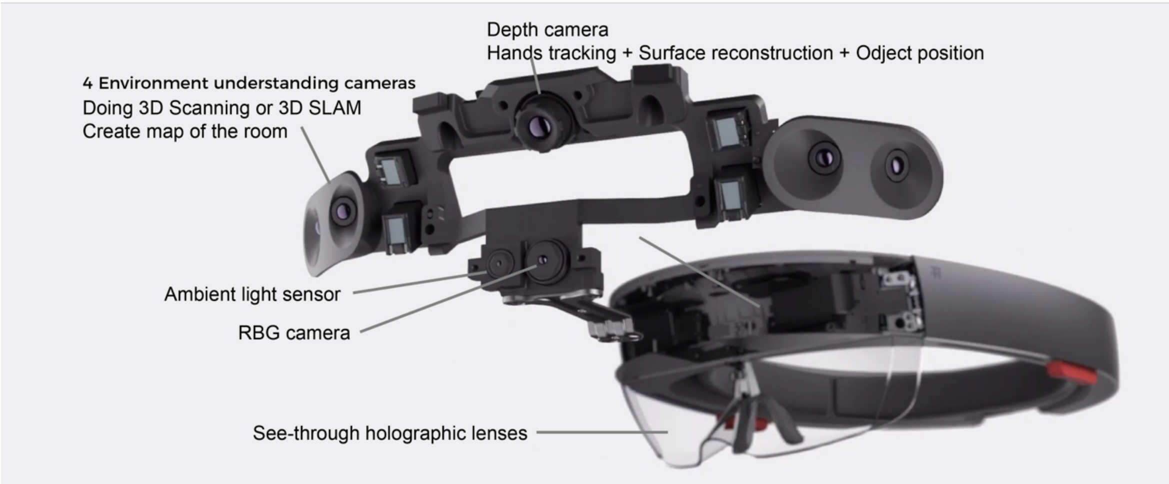


Figure 10: Sensors inside HoloLens

HoloLens has the following sensors (Figure 10): head tracking IMUs (Inertial Measuring Unit); microphones; an energy efficient depth camera with 120°×120°FOV(field of view) an RGB photo / HD video camera; 4 greyscale environment understanding cameras; an ambient light sensor.

The environment understanding cameras are unique as they work with the depth camera to track the head, hands and the surrounding environment

HoloLens has features including: Spatial mapping; Spatial anchor and coordinate system; Spatial sound; Gesture recognition; Voice recognition; Head tracking.

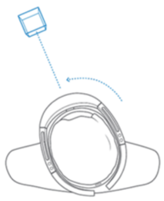
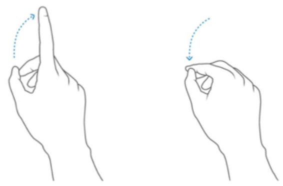
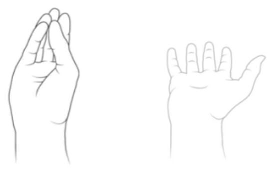


Figure 11: Gaze recognize and head-tracking



(1) (2)

Figure 12: Air tap (1) First gesture (2) Second gesture



(1) (2)

[3]Figure 13: Bloom (1) First gesture (2) Second gesture

HoloLens uses sensual and natural interface commands: gaze, gesture and voice. (Figure 11) There is a while circle which appears in the direction of the user's gaze. The while circle would move with head. The circle works like a cursor and allows the user to target whatever the user is perceiving. (Figure 12) An air tap gesture selects elements or any virtual application or button. (Figure 13) A "bloom" gesture is used to access the main menu. There are other gestures for manipulating a hologram like tap and hold, drag and drop.

Users can use voice command to interact with a hologram directly. HoloLens has own audio assistant "Cortana" like Siri. Users can say "Hey Cortana" to bring up Cortana and ask her questions.

Unity is a 3D game engine which is recommended by Microsoft for developing HoloLens applications. Windows Holographic APIs provide a range of building blocks for interfacing with the HoloLens device. Microsoft developed the Unity HoloToolkit, which provides additional components for developers like spatial mapping and so on.

The developer can use maker tacking and marker-less tracking with Vuforia plug-in for Unity.

HoloLens still has a lot of limitations as follows:

- Limited field of view
- Relatively heavy weight for a headset
- Limited battery duration: 2-3 hours active use
- Limited memory: 64GB
- Not suitable for outdoor
- Not able to recognize black color
- Gesture recognition sometimes not sensitive

However, the technology can be improved very fast nowadays. The HoloLens 2 is about to be released the second quarter of 2019. It is reported that HoloLens 2 has already overcome some limitations like limited field of view, the short battery duration and gesture recognition

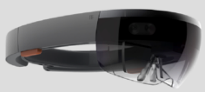
[3] Image source: https://www.microsoft.com

sensitivity (Faulkner, 2018). There are also solutions for outdoor use (Neil, 2018). An additional lens below the HoloLens sensors and cameras can help HoloLens work outside even with bright light.

2.2.2. Comparison with other AR see-through HMDs

There is a general comparison with other AR see-through HMDs on the market. The other devices are Magic Leap One (creator version) and Meta 2. Table 1 compares the three devices with regards to function features, some hardware characteristics and the current limitation. The comparison shows Meta2 is tethered to computer, which has less freedom. Although the Magic Leap One has very similar functions as the HoloLens, and a bigger field of view, the experience is not dramatically better. Since the Magic Leap One was released in September 2018, the development sources at the time of this projects are not rich enough compared with the HoloLens. This is why the HoloLens was chosen for this project.

Table 1: Comparison of 3 mixed reality devices' characteristics

Device	 Hololens	 Magic Leap One	 Meta 2
Battery	2-3 hours	3 hours	tethered to computer
Field of view	35 degree	40 degree	90 degree
Weight	579 g	345 g	420 g without cable
Stand alone	✓	✓	✗
Scan black colour	✗	✗	✗
Outdoor use	✗	✗	✗
Spatial mapping Spatial anchor coordinate system	✓	✓	✓
Gesture recognition	✓	✓	✓
Voice recognition	✓	✓	✓
Head tracking	✓	✓	✗
Spatial sound	✓	✓	✓
Development	Unity Hololenstoolkit ARtoolkit	Unity LumiSDK	Unity Meta SDK
Release time	March, 2016	September, 2018	March, 2016

2.2.3. HoloLens application

A web research of HoloLens applications has been carried out, which yielded a series of application that are similar to those reviewed in AR applications research. Like the head-mounted device used in the mentioned literature, HoloLens can provide spatial information to help the user understand the environment more easily and quickly.

Additionally, Seiger et al (2017) developed a HoloLens application with which users can control physical devices via HoloLens (Figure 14). Virtual control interfaces are attached to the corresponding devices. The user can use gestures to interact with these in order to for example turn on the lights

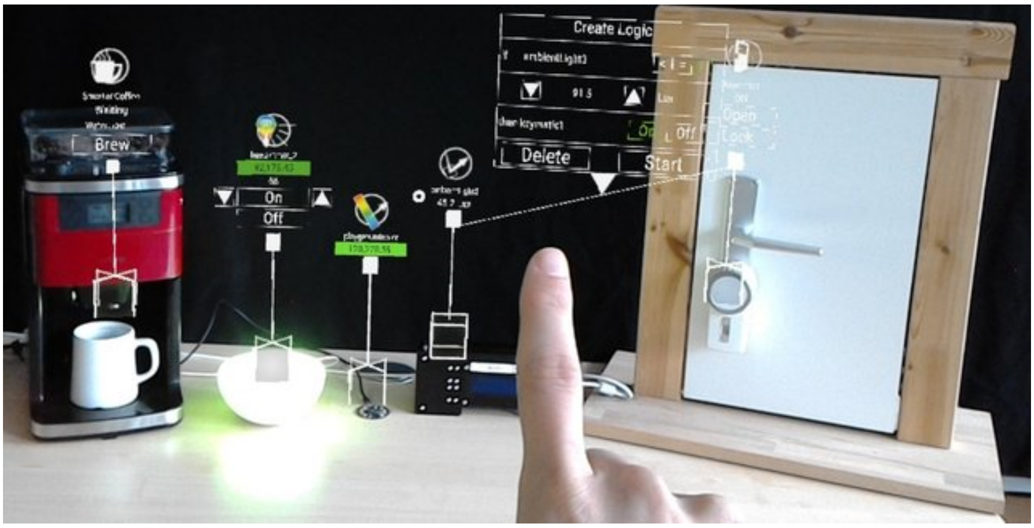
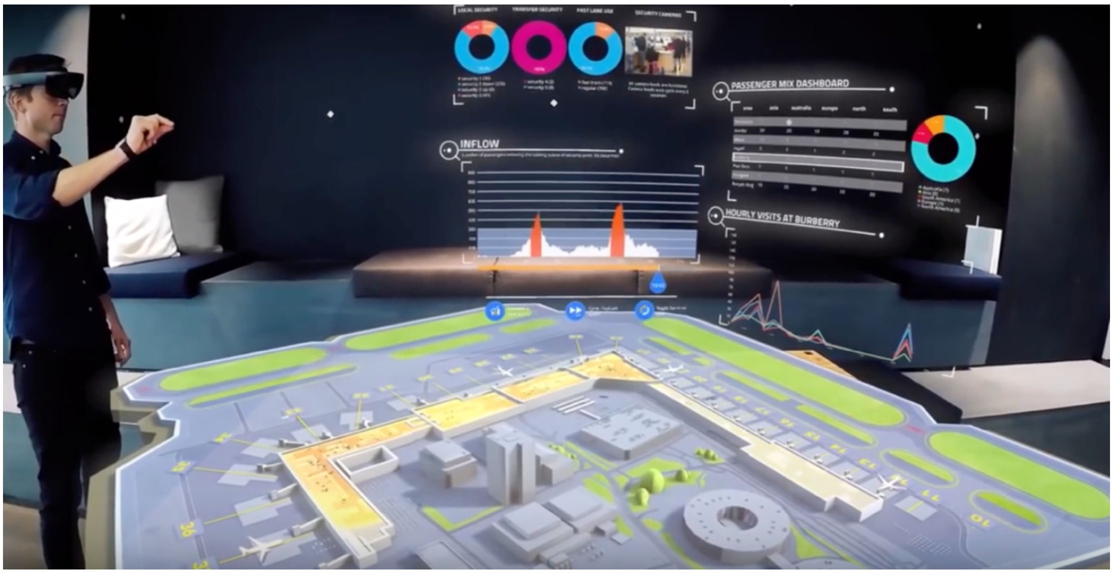


Figure 14: The user see control interface via HoloLens and turn on the light via gesture (Seiger et al., 2017)

HoloLens can visualize a small virtual reality environment like SITA lab (2017) did. The user can see a virtual airport representing the real situation. The user can have an overview of the overall situation via this virtual reality environment (Figure 15).



[4]Figure 15: The user sees a virtual airport via HoloLens by SITA lab, 2017

4 Image source: www.youtube.com

2.2.4. Key insights

HoloLens as a head-mounted AR device, can be a good option for Royal IHC to explore Augmented Reality. In addition to its gaze-based interaction method, user can also interact with virtual content with controllers like the X-box controller. The interaction method should be selected according to the use case.

The application of HoloLens in the industry can provide information with its spatial property. HoloLens can allow the user to sense and control real devices via gesture. Besides, HoloLens can even create a small virtual reality environment to help the user have an overview of the whole situation. When designing HoloLens application, the designers can image more functions that can be implemented in HoloLens based on those insights.

3.User research

The purpose of user research is to understand the target user group. In the case of this research the user group are novice dredge operators. This section highlights specific findings from user interviews, like the typical tasks and problems of this user group.

3.1. Research questions and methods

The research can help to answer the research questions defined in chapter 1:

- What are the problems for novice operators during their dredge control work?
- What kind of support do novice operators need?

Some sub-questions are created according to the two research questions. The position of the answer of each question is provided:

- What is the definition of novice operator? Answer: 3.3.1. Novice operator
- How does their working environment look? Answer: 3.3.2. Physical environment
- How are the elements of their working procedure? Answer: 3.3.5. Task analysis
- What are the problems they have during their dredge control work? Answer: 3.3.7 Problems

In order to answer these questions, the following methods have been used: interviews, observation and company document study.

The main problem of this research was, that it is hard to get access to the novice operators. Royal IHC is not a dredge company. The company does not hire many dredge operators. As a compromise, the research has been carried out with Royal IHC employees who are experienced operators and trainer of dredge operators. There have been two experienced operators and two trainers involved. The observation of task execution has been carried out with one experienced dredge operator and one trainer during their control work in the simulation room. The other experienced dredge operator and the other trainer were interviewed in the office.

The company documents consist of the system manual and previous graduation research reports.

3.2. Results

3.2.1. Novice operator

Novice operators are defined as employees which are able to operate the basic procedure of dredging but do not have more than 2 years working experience. The basic procedure means operating different dredge component safely and have steady productivity.

Novice operators are almost all male with an average age between 20 and 30 years. Usually they will have medium technical degree level education. Novice operators should have a health check with tests of eyesight and physical fitness etcetera like all seamen.

Novice operators are trained for dredging by the dredging companies. Training consists of training on shore with theory and on a simulator with an instructor and then practicing on board guided by a colleague. This instructor is also used to be a dredge operator, and has a lot of experiences (Brantjes, 2011).

Almost all operators have the goal to achieve a high productivity since they are paid by productivity. Novice operators would have the same goal in mind. Besides, novice operators also try their best to prevent any damage of the dredge equipment.

3.2.2. Physical environment

(1) (2) (3)

Figure 16: The dredge cockpit and illustration of the buttons and joysticks on left armrest.

(1) Dredge control chair (2) 5 screens in front of the chair (3) Illustration of control pad on left armrest

The physical environment of the dredge operators includes the tools and working environment. There are a hopper control chair and four touch screens placed in front of the chair for the operator, which are needed to perform their control tasks (Figure 16). The hopper control chair is equipped with controls like joysticks and buttons in the armrests. There is also a small control screen on the right armrest of the dredge control chair. The buttons and joysticks are mainly used to control the winch and gantry of the two suction tubes. Figure 16 shows the distribution of the buttons and joysticks on left armrest. Those buttons and joysticks on the armrests are in almost the same but in symmetrical arrangement.

There are two different software systems required for dredge control work. The integrated Dredging Control System (called SCADA by operators) enables efficient monitoring and control of vital dredge process equipment either manually, automatically or through the use of artificial intelligence. It is the main system for dredge operators to control and monitor the dredge process. The Figure 17 shows the interface for controlling and monitoring loading process of the suction tube PS.

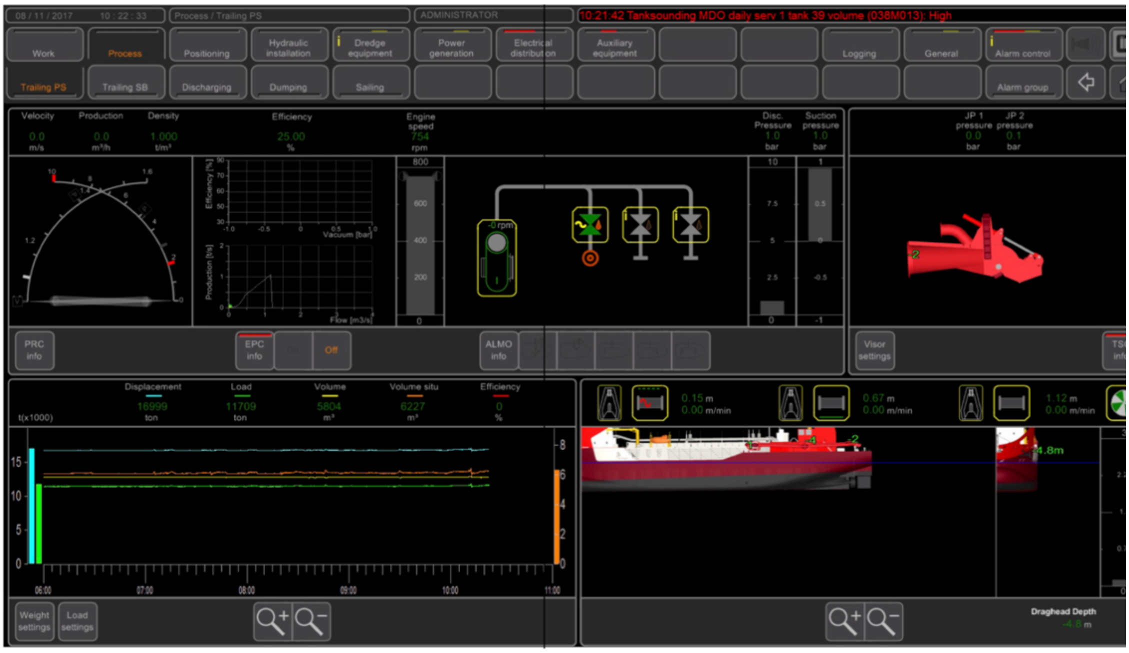


Figure 17: Trailing PS (SCADA page)

The other software system called Dredge Track Presentation System (DTPS) has hydrographic view as well as additional 3D-viewer about the accurate positioning of the vessel and drag heads, pipelines in the dredge location (Figure 18).

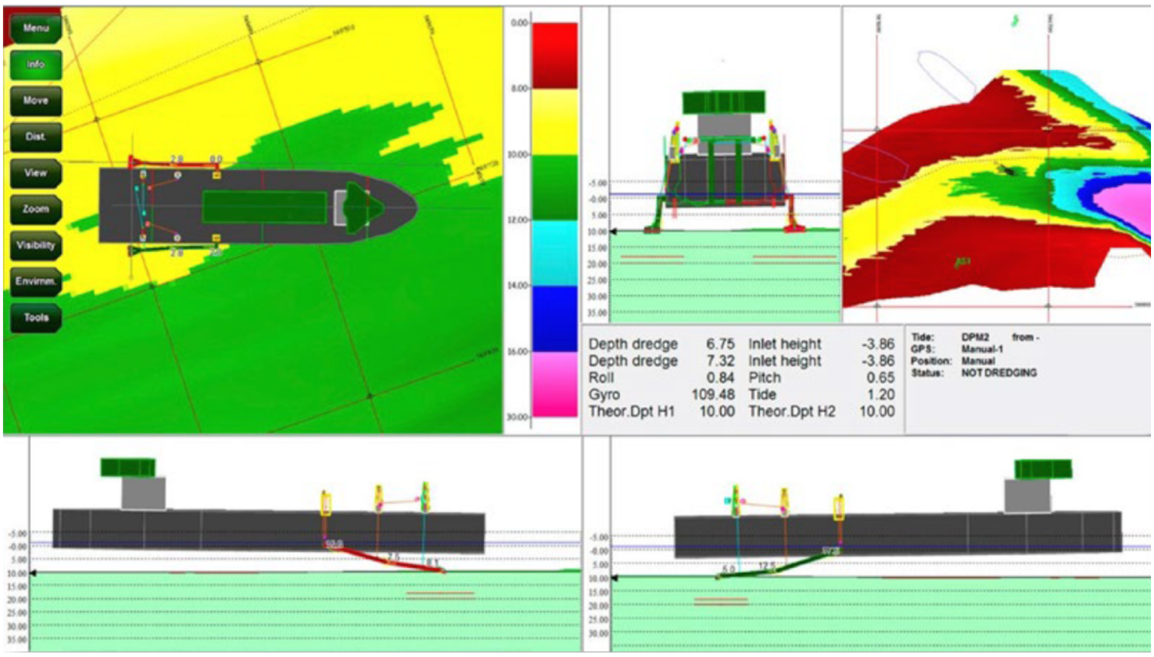


Figure 18: The interface of DTPS

The system provides information to see how deep the vessel is in relation to the seabed. The operator can also check the depth and size of the dredge section to prevent if dredge too deep for some project.

The experienced operators prefer the use of joysticks or buttons for important control. Because the tactile feedback when operating them help operator remind what operation they are doing.

From the interview and observation of cockpit, the two screens in front of the chair are not high. It is because the screens cannot block the operator's view. But the low height is not physically comfortable for operators to scan the screens.

Figure 19: The bridge of Beagle

The control room where the dredge operator cockpit is located is called the bridge. The bridge of Beagle is shown in Figure 19. In the bridge, there is air condition inside so it is always in comfortable weather. The bridge is bright and clean. There will be some vibration when the dredge pump cavitates. The dredge operator cockpit is faced to the cargo. The navigation cockpit is on the opposite side.

The engines sound could be heard but it is not very load. There is sound when different dredge components starting or shutting down. It is good feedback for operators as well. Therefore, these sounds cannot be seen as noise.

3.2.3. Social environment

The first mate, the second mate and the dredge operator are always working together in the bridge. The first mate is responsible for navigation. They communicate with each other a lot during their work. They work as a team in order to achieve a good work performance.

Most communication on the bridge happens between the first mate and the dredge operator. They give each other relevant information about the dredging process, for example, whether they can start or a drag head needs to be emptied for debris. Together they try to achieve the best result.

The first and the second mates discuss specific topics, for example about strategy or repairs. It is important to mention, that the second mate also has rich knowledge of dredging. The novice operator will ask him for help if they come across any problems. The novice operator also gets the knowledge of the optimal setting for high productivity from the second mate. The time for this knowledge accumulation is estimated to be at least 2 years.

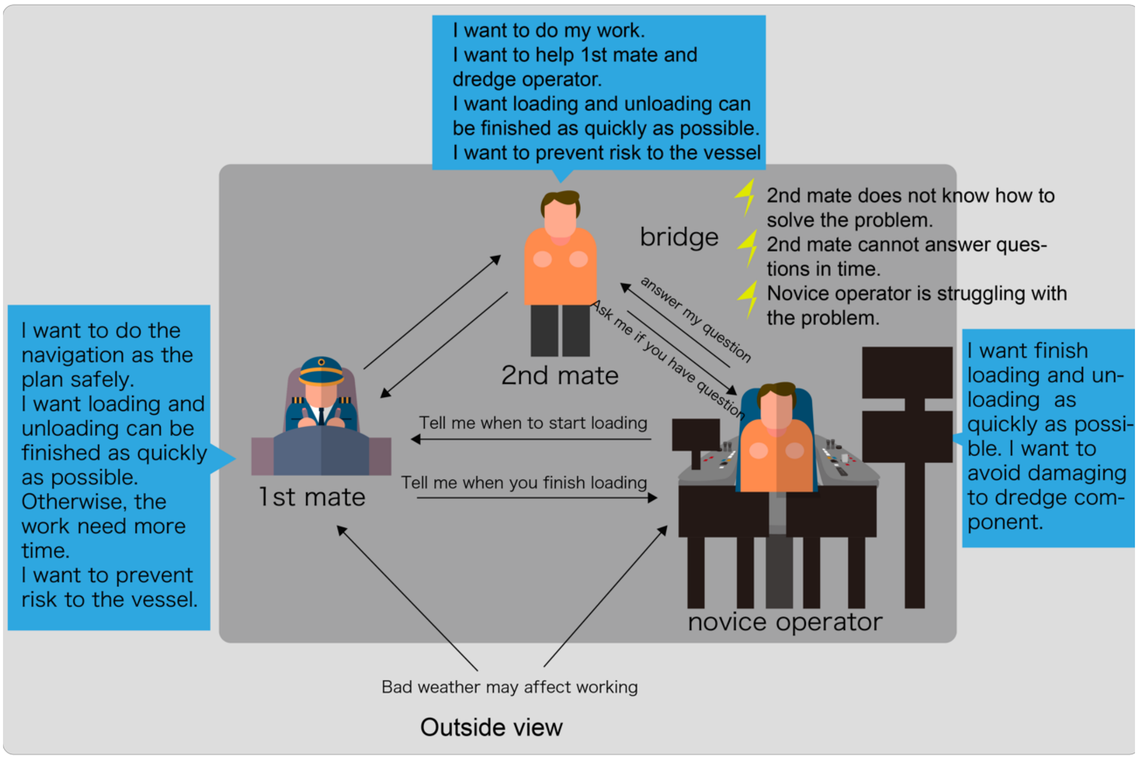


Figure 20: Social model

A social model suggested by Hartson & Pyla (2012) is shown in figure 20. The model shows concerns from different roles and possible problems and its influence. All in all, a fluent communication between first mate, second mate and novice operator is important for the quality of dredge process and the safety of vessel.

3.2.4. Valuable observation and interview details

I observed the 2 interviewees doing some dredge control tasks on the simulator. One of the experienced operators who is the trainer hoisted the suction tubes up and put them back in deck. During operation, he looked outside a lot and saw the tube looked like hoisted at the top. He loosened the control button, but the signal from screen showed the tube was not at the top position. He had to press the button again, which cost more time.

When loading, the two screens in front of the operator are the process interface of suction tube PS and suction tube SP. The screen on the left bottom shows the interface of Pumps and valves. The screen on the left up is DTPS showing the information of seabed. For the whole loading process, all the information on screens are needed. But now all the information is shown to the operator all the time during loading. However, not all the information is always needed. Like DTPS, the operator usually checks for dredge depth, check if the ship is not too close to the seabed at the end and check if the vessel is not out of the dredge section. All the experience operators mentioned they only want to see the productivity, the vacuum and the suction tube position all the time when monitoring loading process.

From the interview, almost all the experienced operator thought it is unnecessary to look outside. Someone even said: “Almost 90 % of the time, the operator is focusing on the screens.” Someone said: “You always want to see outside, although I think it is an unnecessary behavior.” However, they do look at the outside a lot when they really do their tasks in the simulated cockpit.

For the most difference between novice operators and experienced operators, someone said: “The most significant difference is that an experienced operator knows what is important, what is not. He also knows why and what to do when an abnormal situation occurs.” Someone gave an example: “When putting gantry outboard if the vessel is shaking at the same time, a novice operator would put gantry back. It is an instinctive reaction but not right, because the tube would hit the gantry. Instead, they should ask the 1st mate to control the vessel first.”

The trainer also said: “For lowering and hoisting the tube, there is no big problem. The most problem for a novice operator is to get high production. The high production needs an operator’s experience and knowledge of optimal setting of different dredge component.”

There is another investigation after the interview. The investigation is about the average full loading time of Beagle 8 of a novice operator, a medium operator and an experienced operator for a medium sand project. Table 2 shows the results. However, the interviewees also indicated the differences would be bigger for a fine sand project.

Table 2: Average dredging time with Beagle

Skill level	time
Novice	80 min
Medium	70 min
Experienced	60 in

3.2.5. Task analysis

Because of limited time and the complexity of the entire dredging process, the task analysis focuses on the loading process because it is the most important phrase.

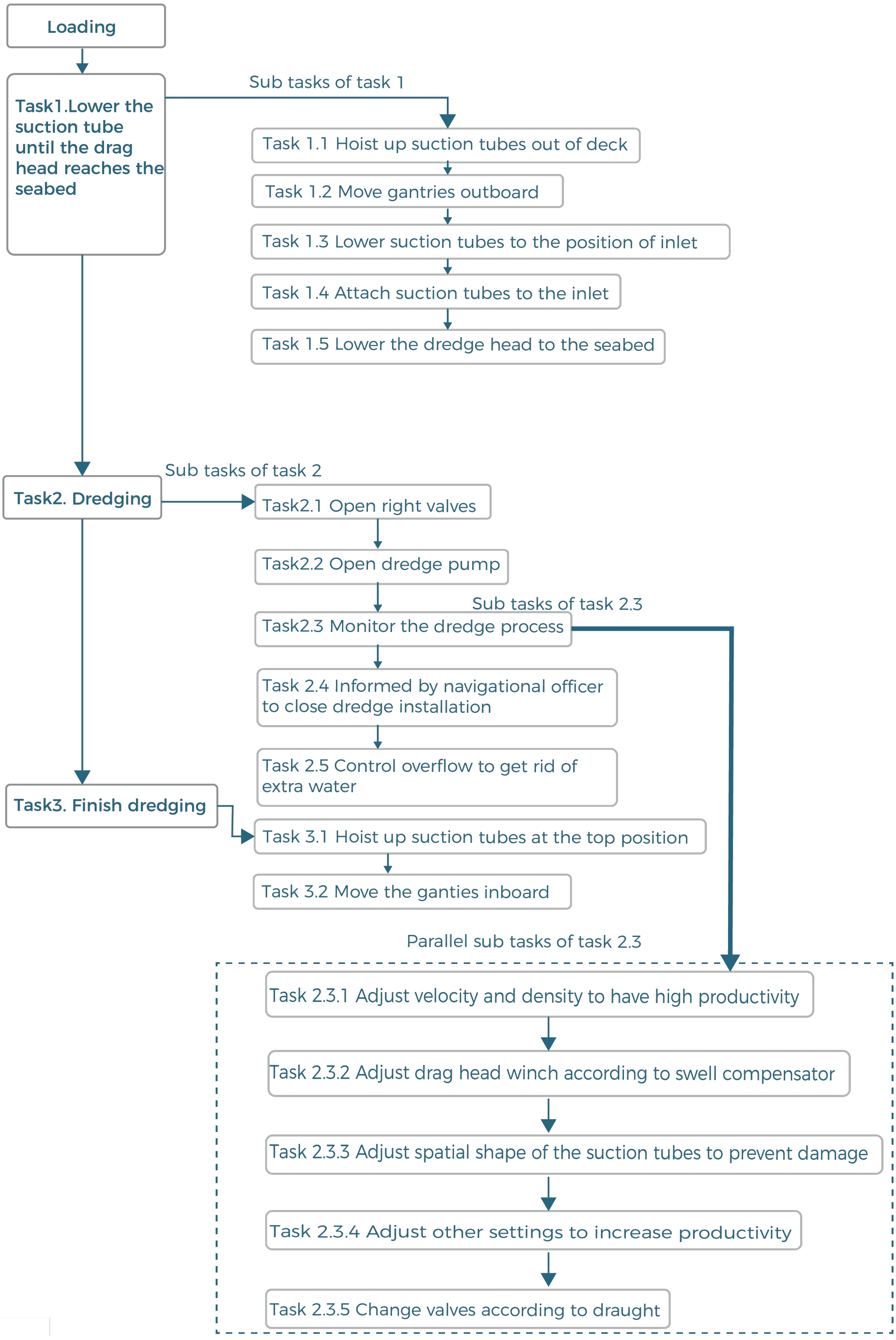
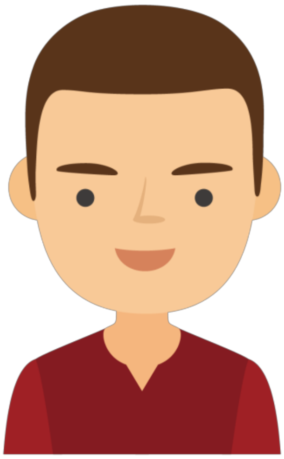


Figure 21: Task flow

The task flow (Figure 21) shows the tasks a dredge operator should do during loading phase. The detailed explanations of the tasks can be found in Appendix 2.

3.2.6. Personas

The analysis is based on the two personas and information collected from interview and observation. The personas are created based on information gathered from 3.3.2 (Figure 22, 23).



Name: Nirav
Age: 28
Nationality: India
Education: High school diploma
Wokring language: English

Working experience: 5 months
Training time: 1 months
Strengthness: Good at mechanical operation like handling with joysticks.

Personality: I like rules and principles. I like my job because it involve reparing and maintance of dredge equipment.

Goal: I want to get higher productivity. But I want to make sure my job is done safely at first.

Figure 22: Persona 1 Nirav

Name:Nicolas
Age: 26
Nationality: Argentina
Education: Bachelor
Working language: English

Working experience: 3 months
Training time: 1 months
Strengthness: Bad at handling with joysticks, bottons.
Weakness: Good spatial imagination.

Personality: I am enegetic. I am always willing to try new things like new technology.

Goal: I want to get higher productivity. I am always willing to try different settings to see how it works.

Figure 23: Persona 2 Nicolas

3.2.7. Problems

The task and the problem the two novice operator personas may have are identified and visualized as a map below (Figure 24). If there are tasks, where both personas would have the same problems, they are grouped together in the map. Different colors are used to distinguish different problems.

In general, there are yellow, blue and orange problems for the novice operator. The yellow problem is that the novice operator cannot understand the position of gantries or winches correctly. The blue problems mainly refer to the need of a high mental task work required to understand the position and spatial shape of two suction tubes as well as to control two tubes at the same time. The red problem refers to the need of high concentrations and mental work to understand the situation towards getting high productivity.

Task	Task 1.2 Move gantries outboard Task 3.1 Hoist up suction tubes at the highest position Task 3.2 Move gantries inboard	Task 1.3 Lower suction tube to the position of inlet Task 1.5 Lower drag head to the seabed
Prob-lem	Through the observation of experienced operator doing dredge control work, it is found that operators often look outside to see the winch, gantry and tube. The 2 novice operators would look at the gantries and winches moving through the window. They may receive critical signals with a delay or make wrong decisions. For example, they may release the control button after the the gantries are already outboard appear for a while. Or they stop moving gantries before gantries are really outboard.	For those tasks, the operator has to oberserve the spatial shap of two tubes, the right symbols and control the tubes at the same time. Nirav may need more mental work to understand spatial shape of the two tubes through software interface at the same time. Nicolas may have problems on controlling winches with joysticks. He needs more effort to control the winch.
Task	Task 2.3 Control the dredging pro-cess	
Prob-lem	The novice operator does not have a mature mental modle yet. The 2 novice operators may not able to understand the situation and make right decisions quickly. They need high concerntration and a lot of mental work to do the task. Meanwhile, they do not have enough experience of the best settings for optimal productivity for different conditions.	

Figure 24: Task and problems map

3.3. Conclusion

The user research helps understand the working environment and identify the dredge control tasks that the novice operator has to do. Different problems of different tasks are analyzed based on personas of novice operators. It is expected that the HoloLens may support novice operator do these tasks. However, the tasks are too complicated that it is impossible to involve all tasks for conceptualization later. The tasks would be selected. The problems found of the selected tasks can help generate design requirements.

4. Conceptualization

The purpose of the conceptualization is to generate different HoloLens support functions for different tasks. The conceptualization would be based on the tasks and problems identified in user research as well as HoloLens ability to

It is impossible to cover all the tasks identified in user research in this project, because of the limited time of a graduation project. This is why Task 1.1, Task 1.2, Task 1.3, Task 1,4 and Task 1.5 (compare the task table in Figure 21) have been selected. Task 1.2 covers the yellow problems (awareness of gentry positions) and Task 1.3, Task 1.5 cover the blue problems (understand the dredge head position). The problems and the colors have been explained in Figure 24. Task 1.1 and Task 1.4 are also selected to make the process more consistent and complete.

According to the task analysis, the task requirements for each task are listed in the figure 25 below:

Task	Task 1.1Hoist up suction tubes out of saddles	Task 1.2 Move gantries out-board	Task 1.3 Lower suction tubes to the position of inlet
Requirements	The novice operator should know the suction tubes are out of saddles and stop hoisting up suction tubes.	The novice operator should know when gantries are already outboard and stop moving gantries at the same time.	The novice operator should know the suction tubes are positioned to the inlet. The novice operator should not allow the angle of the upper part and lower part of the tube too small.

Task	Task 1.4 Attach suction tubes to the inlet	Task 1.5 Lower the drag head to the seabed
Requirements	The novice operator should know whether the suction tubes are attached to the inlet and stop controlling trunnion winch at the same time.	The novice operator should not allow the angle of the upper part and lower part of the tube too small. The novice operator should stop controlling drag head winch when drag head is placed on the ground.

Figure 25: Tasks selected and the requirements

Meanwhile, there is a constraint for the concept: The communication between the dredge operator, first and second mate should not be disturbed. (See in chapter 3.3.2.3. Social model)

In order to perform the selected tasks, the operator needs to be aware of the following pieces of information:

- The spatial relation of the gantries and the suction tubes with respect to the environment.
- What the expected situation looks like.
- What should be done to achieve the expected situation.

To understand the spatial information and decide what to do, the novice operator should know:

The position of gantries including:

- If gantries are inboard,
- If gantries are moving outboard, and
- If gantries are outboard.

The position of suction tubes including:

- If the suction tube is lowering/hoisted up,
- If the suction tube is hoisted out of saddles,
- If the suction tube is positioned in the right height for the inlet,
- If the suction tube is attached to inlet, and
- If the drag head is placed on the ground.

The spatial shape of suction tubes including:

- The vertical angle between upper part and lower part of the suction tube (the angle cannot be too big, otherwise the tube would break)

All the information is provided by the sensors in the current system. The information can be classified into two categories in general:

- The spatial state of gantries and suction tubes, and
- The signals of some specific situations of gantries and suction tubes. (As the suction tube is controlled by winch wires, the position signal of the suction tube is actually signals of winches).

4.1. Concepts

The information, which is needed to complete the selected tasks, is already provided by the current system. The core of the concepts is to extract this information and provide it in a more user-friendly way. The operator can then directly see the essential information through the HoloLens and will not be disturbed by other information, which is not relevant at the moment. The operator does not need to switch attention between screens and real world either. However, the essential information can be provided through the HoloLens in different forms. At first, three different concepts have been developed, how this information could be provided.

4.1.1. Concept 1:

Figure 26 provides a visualization of the first concept. The main idea of this concept is to reuse as much as possible from the current interface. The sketch in the background represents the real world, which the operator can see through the window. The colorful illustrations represent virtual information rendered by the HoloLens. In this concept, the operator still controls gantries and suction tubes via the control chair. The operator can directly see the icons of the gantries and the suction tube, through the HoloLens. The icons are chosen from the current system and the operator is already used to them. When the suction tubes are underwater, a visualization of suction tubes and seabed from a third person's perspective is used. This is an integration of the side view and front view of the suction tube, which is provided in the current system. The angle is marked on the suction tubes. There is a line with arrows between drag head and seabed. The value of distance shows beside the line (Figure 26 Concept 1-2).

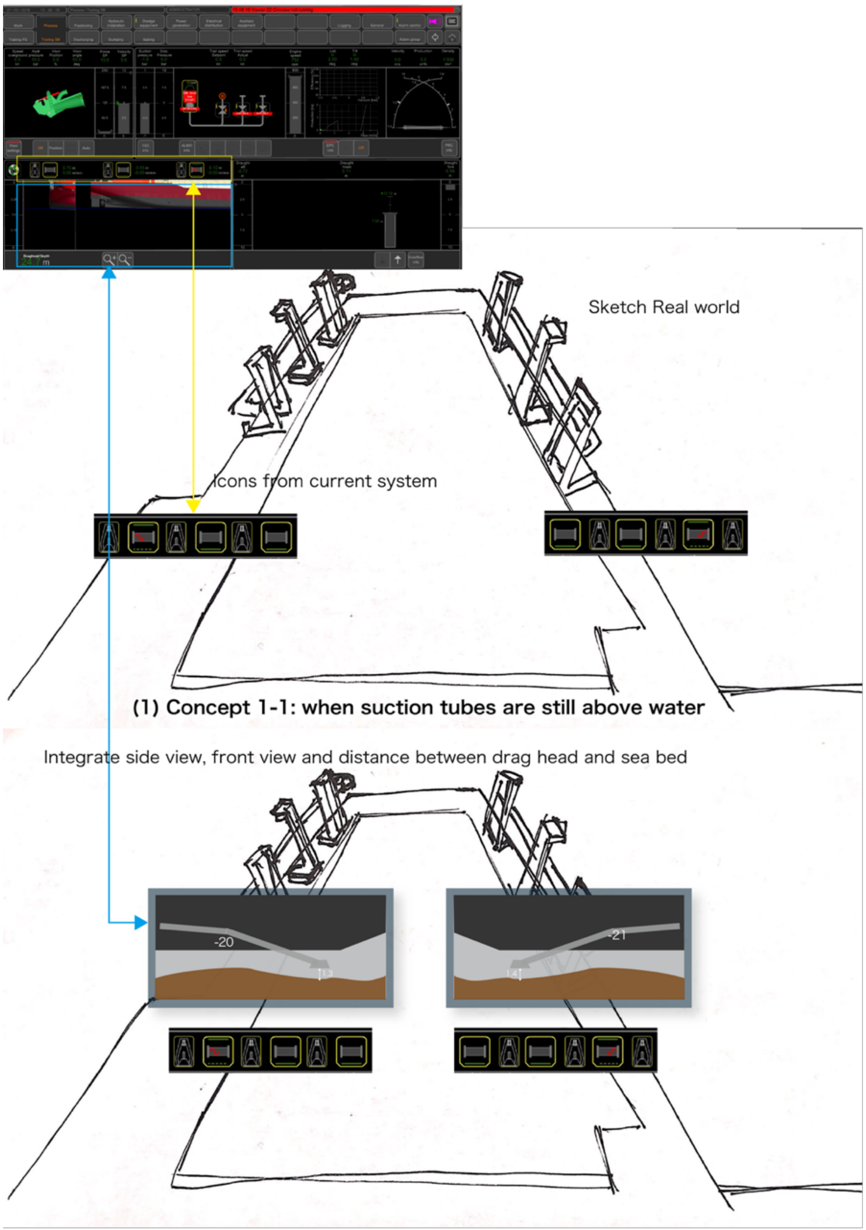
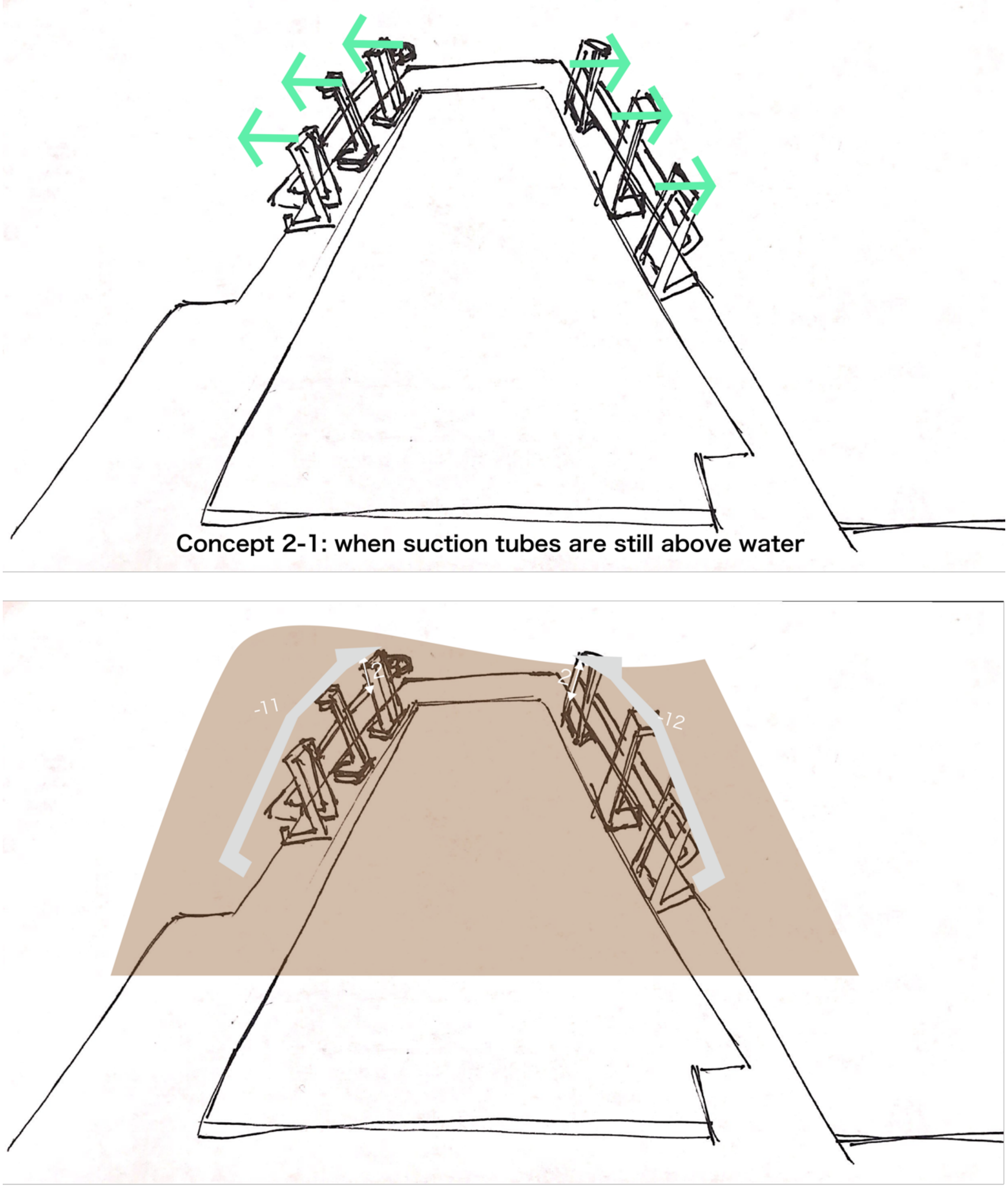


Figure 26: Concept 1: Make use of the current system interface

4.1.2. Concept 2:

Concept 2 would make use of the real world but augment the real world as much as possible. The operator still controls gantries and winches via the control chair. When the suction tubes are above water, there are simple visual icons, which align with gantries and suction tubes (Figure 27). When suction tubes are underwater, the suction tubes and seabed are visualized align with the real tubes and seabed from the operator's perspective. The distance between drag head and seabed and the value are visualized in the same form of Concept 1(Figure 27 Concept2-2).



Concept 2-2: when suction tubes are underwater

Figure 27: Concept 2: Augmented reality

4.1.3. Concept 3:

The concept 3 tries to use the full ability of the HoloLens. The idea is to use a small virtual model of the vessel and seabed, which represents the state of the real vessel and seabed (Figure 28). The operator can control gantries and winches via gesture. The operator can know the signals of specific situations of gantries and winches via sound feedback. The distance and angle are visualized in the same form of Concept 1 and 2.

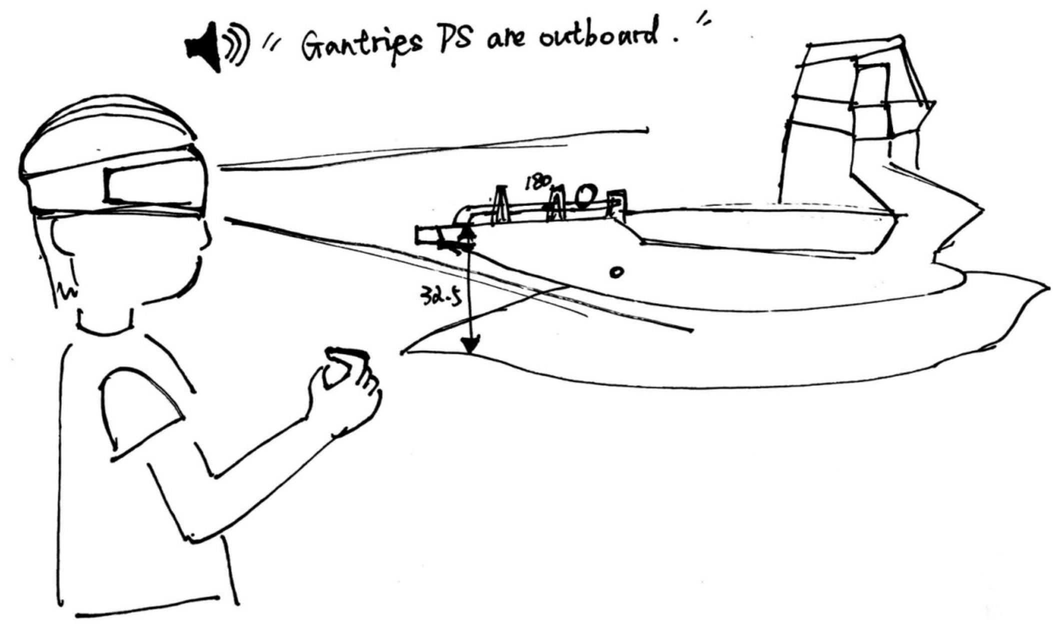


Figure 28: Concept 3: A virtual vessel

4.2. Evaluation of the concepts

The concepts are evaluated from different angles. For providing the signals of specific positions of gantries and suction tubes, Concept 2 should work best in the scenario. First of all, comparing Concept 1 and Concept 2, icons align with gantries and winches need less mental work because they do not need mentally transform (Tang et al., 2002). In addition, the icons like arrow are more simplified than the current icons. They are easier to understand. Furthermore, Sound feedback in Concept 3 would disturb communication with crews.

For knowing the spatial state of gantries and suction tubes, the operator may not be able to see two tubes at the same time in Concept 3. This is a severe issue for the tasks. The perspective of Concept 3 and Concept 1 is almost the same. It is a third person's perspective. The perspective of Concept 2 is like a first person's perspective. It is not sure which perspective works better.

For controlling gantries and winches, the controlling method in concept 3 is not suitable for the scenario. The operator needs quick control of winches. But the reaction of gesture control with HoloLens is not sensitive enough. Thus, it is better to control gantries and winches via control chair.

For implementation, according to the Unity programmer, it is difficult to render the whole model of the vessel through HoloLens. The model is too delicate that most of the memory space would be used to render it. It would take more time to simplify the 3D model. The comparison of effort on making working prototype is: Concept 3 > Concept 2 > Concept 1

Therefore, the concept that the operator sees the simple visual icons align with gantries and suction tubes is chosen. The operator also knows the overview of suction tubes and seabed through HoloLens when the suction tubes are underwater. But the perspective of the overview visualization is not sure. One is the operator's first person's perspective. The other is the third person's perspective.

4.3. Concept detailing

The icons of gantries and winches are designed based on the current icons (see current icons in Appendix 3). The new icons have been simplified in comparison to the current ones. Figure 29 shows the icons used in the final concept and their meaning. The colors of all the icons are the same with the current ones. The arrow of gantries is little bit different from the one of suction tubes. The arrows are designed based on the current icons as well.

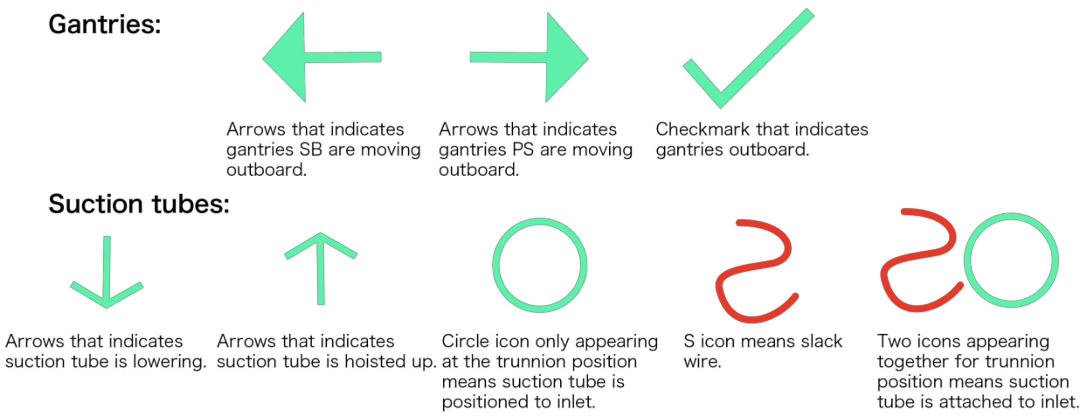


Figure 29: Simplified icons

Figure 30 and Figure 31 show the detailed interface and the interaction with the concept for two perspectives during the control of gantries and winches. Figure 30 shows the third person's perspective. Figure 31 shows the first person's perspective. In both perspectives, the sensor data of vertical angle between the upper part and lower part of the tube is shown align with the tube. The distance between drag head and seabed is visualized by a line and the detailed value is shown beside it when the suction tube is underwater.

When the suction tube is lowered underwater, there are two different perspectives of the overview visualization of suction tubes and seabed.

The perspective of visualization of suction tubes and seabed is different.

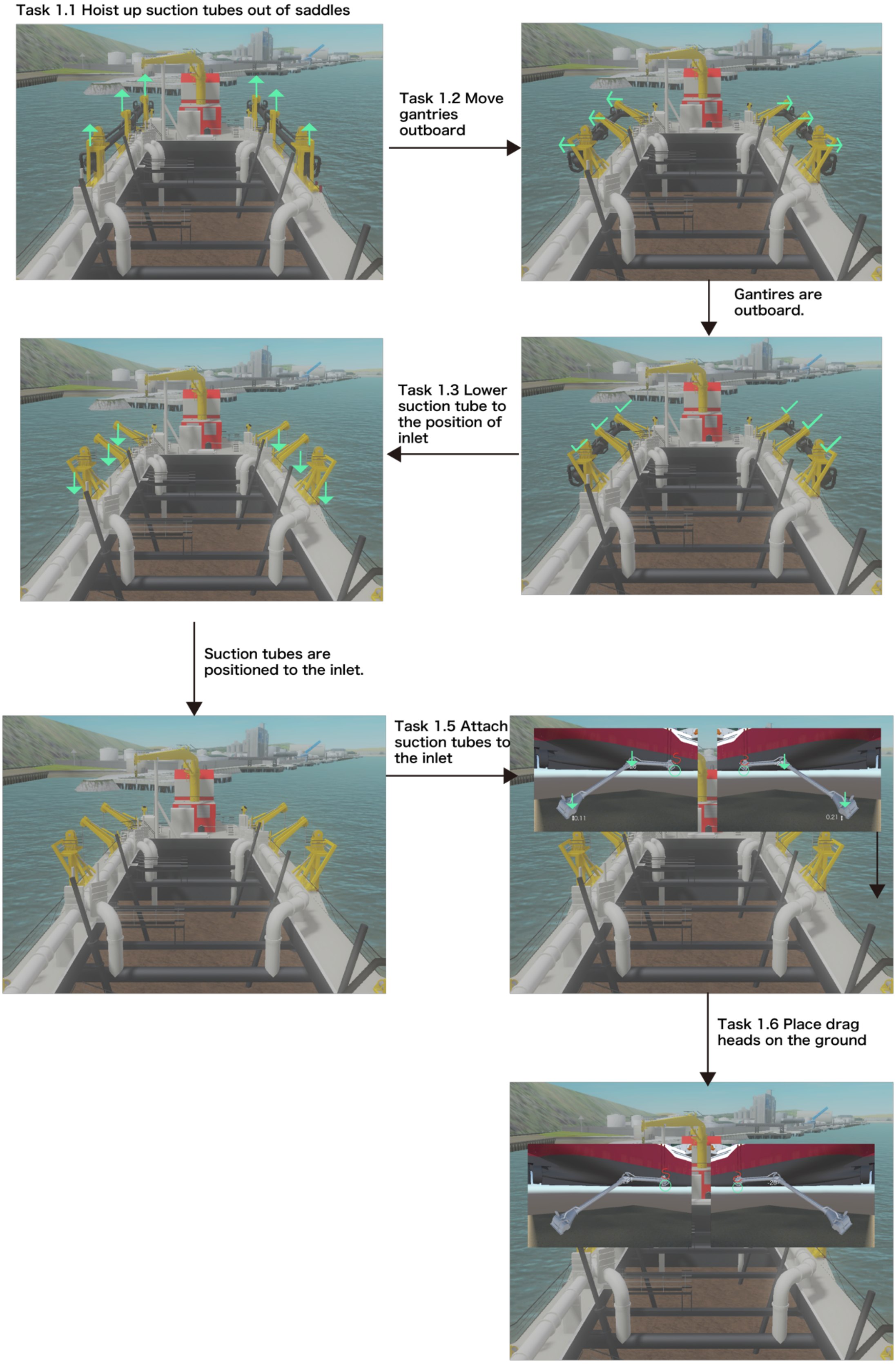


Figure 30: Visual flow of the third person's perspective

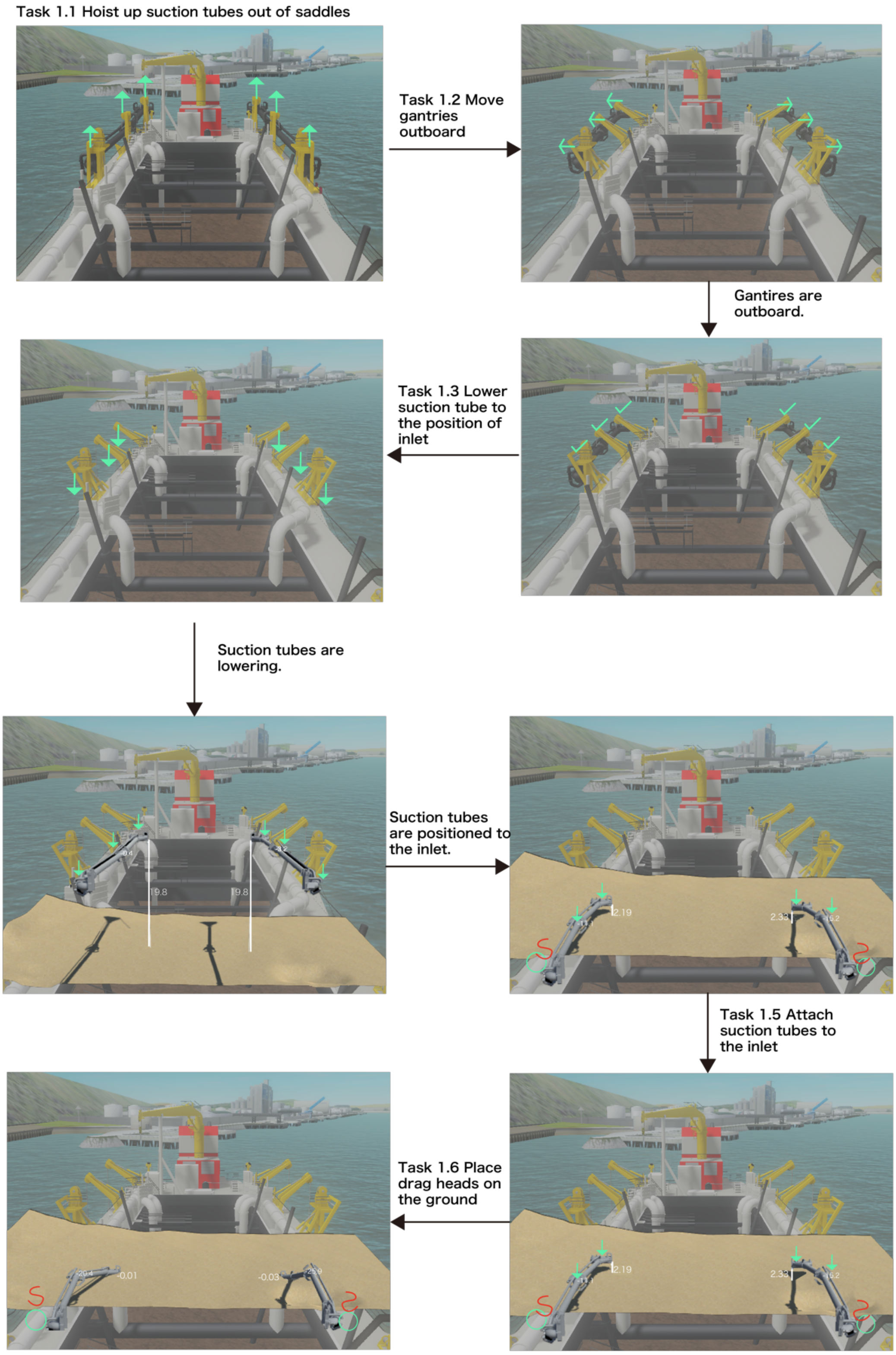


Figure 31: Visual flow of the first person's perspective

4.4. Implementation

The prototypes are developed in Unity 2018 3.1f1 Personal version, Visual Studio 2015 Update 3 and Windows 10 environment. Because it is impossible to work on a real dredger. The prototype should work together with the IHC dredge simulator system which is a simulated dredge control system as well as an outside view simulator which can simulate how a dredge works under control. An X-box controller is also used to replace the control pad on the control chair. The following chapter would explain more detail about the implementation.

4.4.1. Function model

The figure 32 shows the function mode of the prototypes. As mentioned before, the prototypes should work with the dredge simulator, outside view simulator and an X-box controller. The dredge simulator system can create a virtual dredger which can be controlled by the user manually. This system contains all sensor data of the virtual dredger. The outside view simulator can simulate how this virtual dredger looks like in the real work under the user's control. It shows what a dredge operator would see when sitting on the control chair and look through the window. The two systems work with each other.

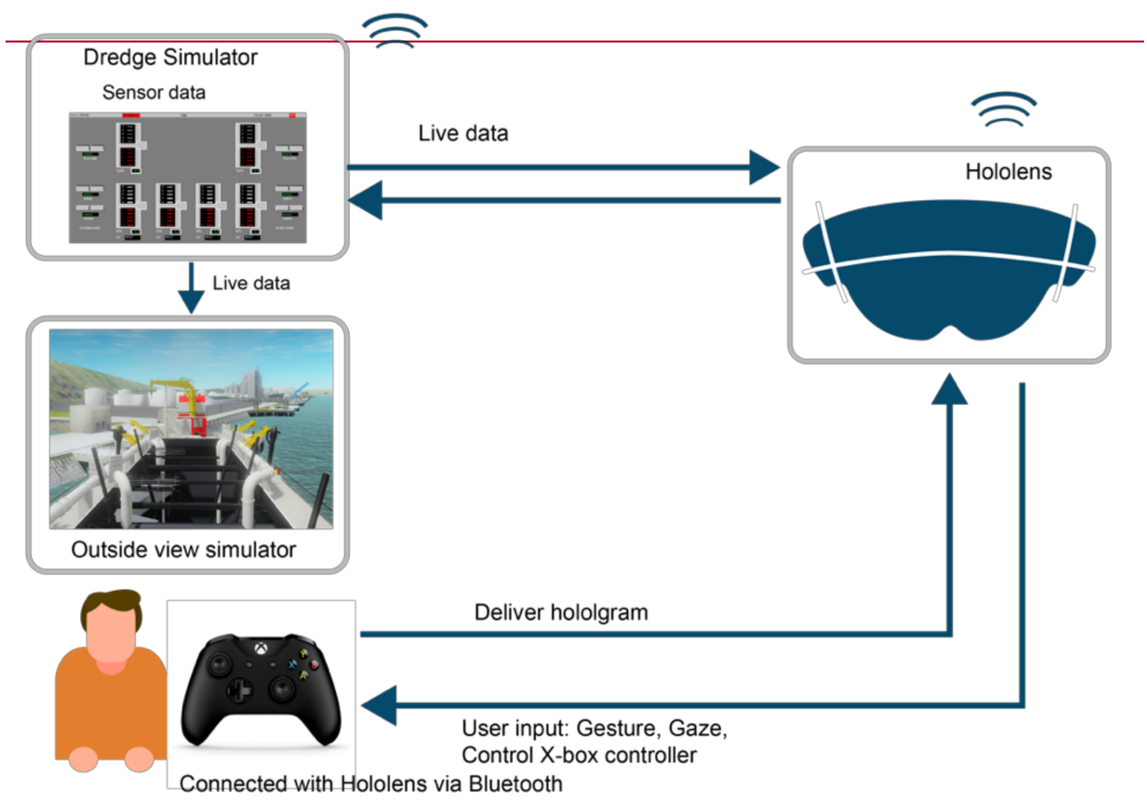


Figure 32: Function model of the prototypes

Thus, the prototypes should work together with these two systems. The computer running dredge simulator and HoloLens should be connected with the same Wi-Fi. X-box controller should be connected with HoloLens via Bluetooth. When the user wears HoloLens, HoloLens will render the essential information which is created based on the live data achieved from dredge simulator. The user should look at a big screen which shows the simulated outside view. The virtual information should align with the simulated view. The user can control the dredger with X-box controller. X-box controller would send the data to HoloLens and HoloLens sends data to dredge simulator. The dredge simulator would achieve data and send data to outsider view simulator and HoloLens. Then, the user could see the virtual information and outside view change after the operation.

4.4.2. Unity

Unity 2018 3.1f and visual studio 2015 are used to develop the prototypes. The figure 33 shows the general development flow of the prototypes. 3D models like gantries, tubes and other components and image source like icons are imported into Unity to create game objects. The game object is the foundation of a Unity project. Game objects attached with components make a project functional. The live data of dredge simulator is saved in the IHC DigiSys platform. Thus, a series of C# scripts with regards to DigiSys are written to create behaviors which works according to live data such as moving the suction tubes after controlling winches. Those C# scripts are seen as behavior component in Unity. The game object like suction tubes created should be connected with DigiSys platform and receive live data. HoloToolkit is also used in order to functions like spatial mapping. Visual studio is used to build and deploy the applications created by Unity in HoloLens.

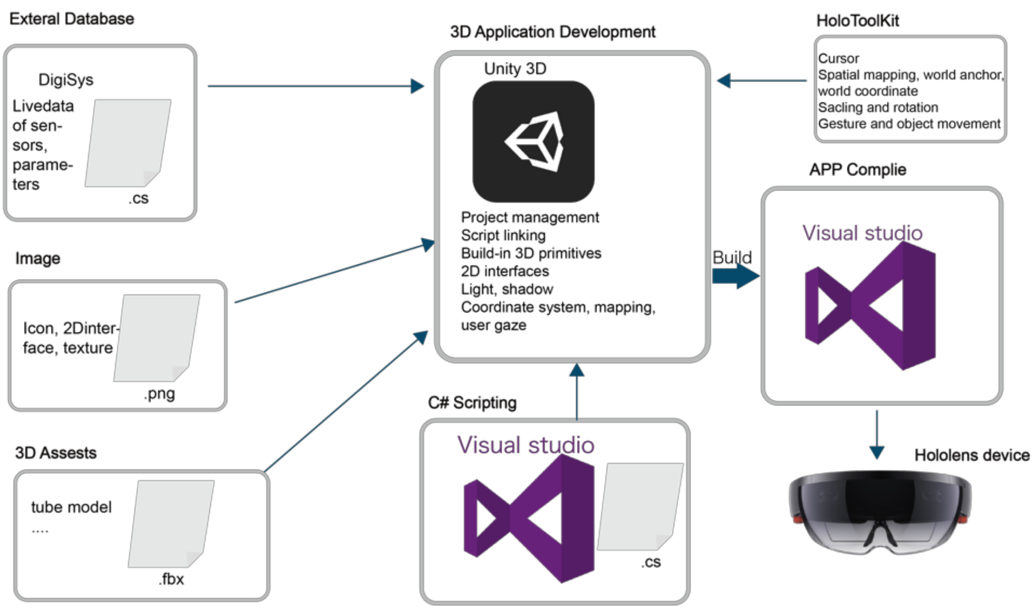


Figure 33: development process with Unity

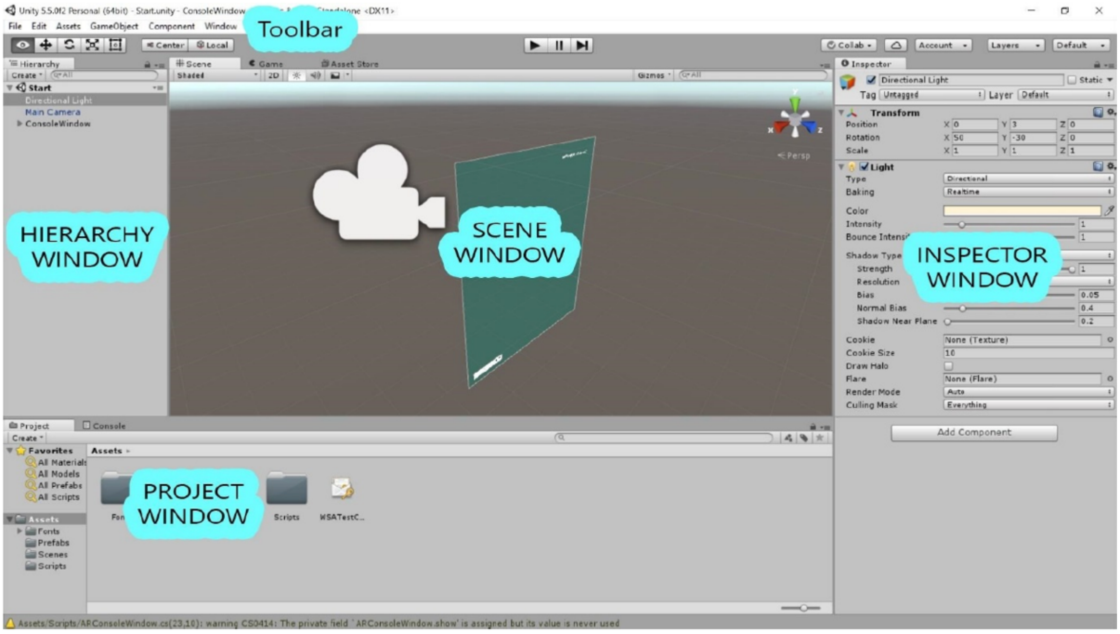


Figure 34: Basic interface of Unity

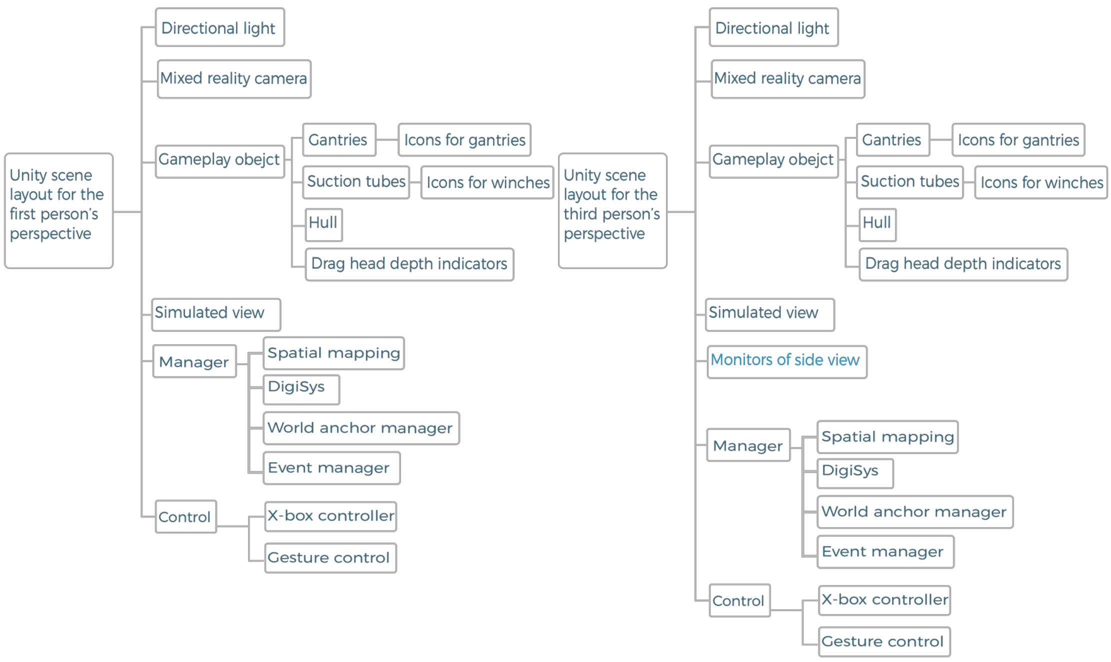


Figure 35: Unity scene layout for two perspectives

Figure 34 shows the basic interface of Unity. There are 4 important windows: hierarchy window, scene window, inspector window and project window.

Figure 35 shows the general Unity scene layout for two perspectives. The main difference is that there are monitors of suction tubes in the third person's perspective.

There is an important issue for the two applications which is to align virtual content to the corresponding position. Figure 36 introduces the process of aligning virtual content. At first, a virtual vessel is created in Unity in real size. Different functions are added into different

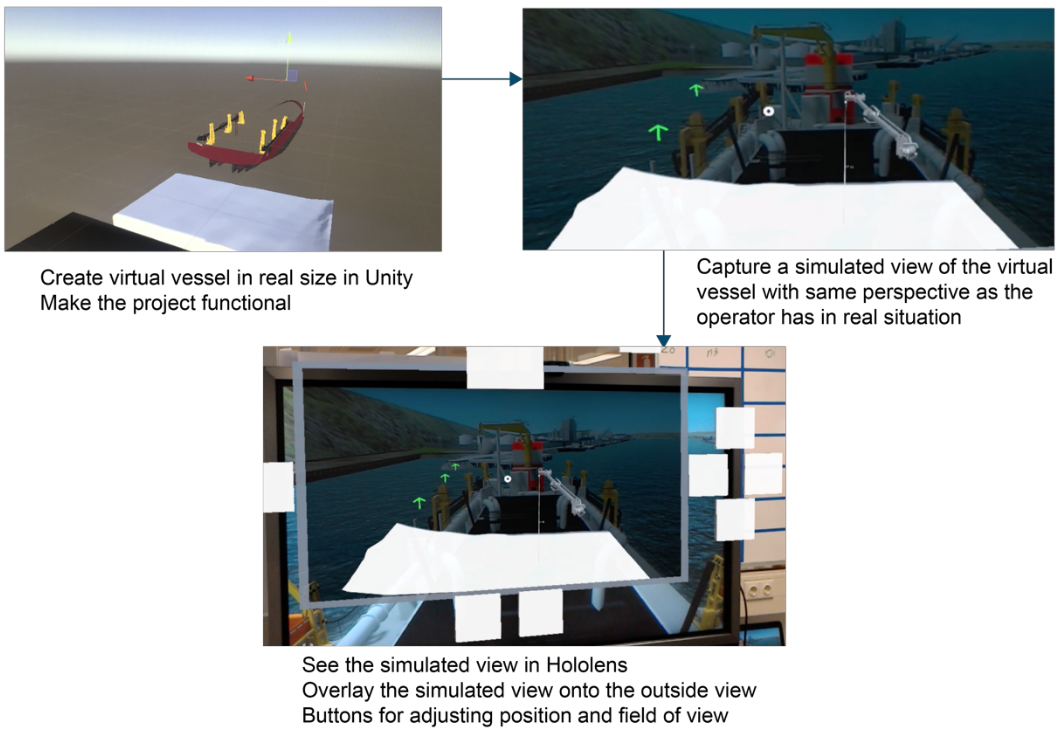


Figure 36: Process of aligning virtual content

equipment of the vessel. Then, Unity can create a simulated view of the vessel with the same perspective as the operator has when sitting on the control chair. Finally, when seeing the simulated view through HoloLens, the user could adjust the position and field of view of the simulated view by buttons. The simulated view should be aligned with the simulated outside view as shown in figure 35.

4.4.3 DigiSys toolkit

There is a DigiSys toolkit which contains all C# scripts about DigiSys. Figure 37 explains this process looks like. The detailed explanations of the functions of the different scripts are following. The detailed explanation of the C# component can be found in Appendix 4.

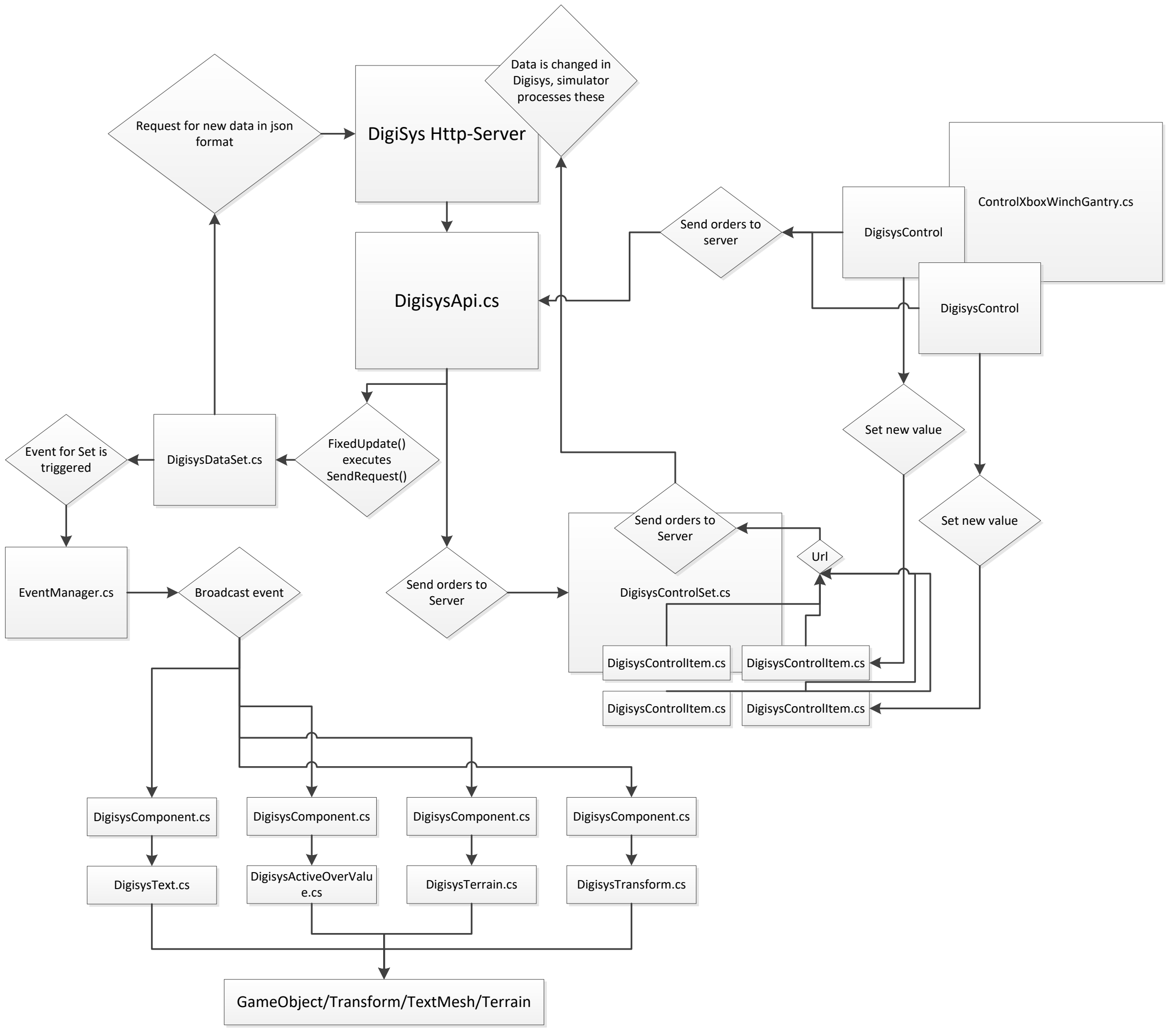


Figure 37: Work flow of Digisys Toolkit[5]

4.4.4. X-box controller

An X-box controller is used to replace the control pad on control chair. The programmer and I work together arranged the functions of this controller. Figure 38 shows how the X-box controller controls winches and gantries. The two triggers on the side are used to select a different side. The user should always hold the trigger to select different side. For the joysticks, the user should always hold them to control the corresponding winches. However, for buttons, the user only has to press them once and the gantries or winch would always move.

[5] Image source: Company document

Figure 38: X-box controller functions

4.4.5. Contribution

Most work with DigiSys and basic scene building is done by the Unity developer hired by IHC which contains:

- Build basic scene (spatial mapping, world anchor, gesture control)
- Connect DigiSys with gantries and suction tubes
- Make icons work
- Create a simulated view
- Make X-box controller work

There is also a lot of work I did myself which includes:

- Interface and interaction design
- Create two monitors for the third person's perspective
- Adjust game objects
- Adjust font and text size
- Test with dredge simulator and outside view simulator
- Build and deploy application according to the test environment

5. Concept evaluation

The purpose of the concept evaluation is to find out, if the concept can help novice operators complete the selected tasks. Meanwhile, the evaluation is aimed to find out which perspective works better in terms of effectiveness, intuitive use and learnability.

5.1. Research question

The main research questions are:

- Can HoloLens help the user have better performance and user experience than the current system?
- With which perspective the participants have better performance and user experience when doing their tasks?

According to research questions, there are two hypothesizes:

Hypothesis 1: It is better to complete dredge control task (task 1.1 to task 1.5) through HoloLens than the current system.

Hypothesis 2: Perspective one works better than perspective two.

5.2. Experimental design

There are two difficulties in this project. One is that the company can only provide 4 participants with the required specific domain knowledge of dredging and the current system of Beagle. However, the subject size is too small. The other one is that it is difficult to compare the applications with the current system. Only the 4 participants can give their personal opinions when comparing with the current system. Thus, I expand the subjects to those who has no knowledge and experience before. Those people are students from the faculty of Industrial Design of Tu Delft. There will be two groups of participants: 4 IHC employees and 14 students. All the students are those who have positive attitudes towards augmented reality.

Thus, there are two groups of subjects. The study is a between subject study. The test process for two groups are the same. Each group would be divided into two small groups. One group tests the perspective one. The other group tests the perspective two.

Qualitative data and quantitative data was be collected in order to study the task performance and human experience of the two perspectives. Task performance can be studied by observation, protocol study and think aloud technique. Human experience can be studied by questionnaires like NASA TLX (Hart & Staveland, 1988), QUESI (Hurtienne & Naumann, 2010) and SWRT (Taylor, 2017). Qualitative data collected from IHC employees can help make sure if the application proposed works better than the current system. Quantitative data collected from two groups can help find out which perspective works better.

5.2.1. Test set up

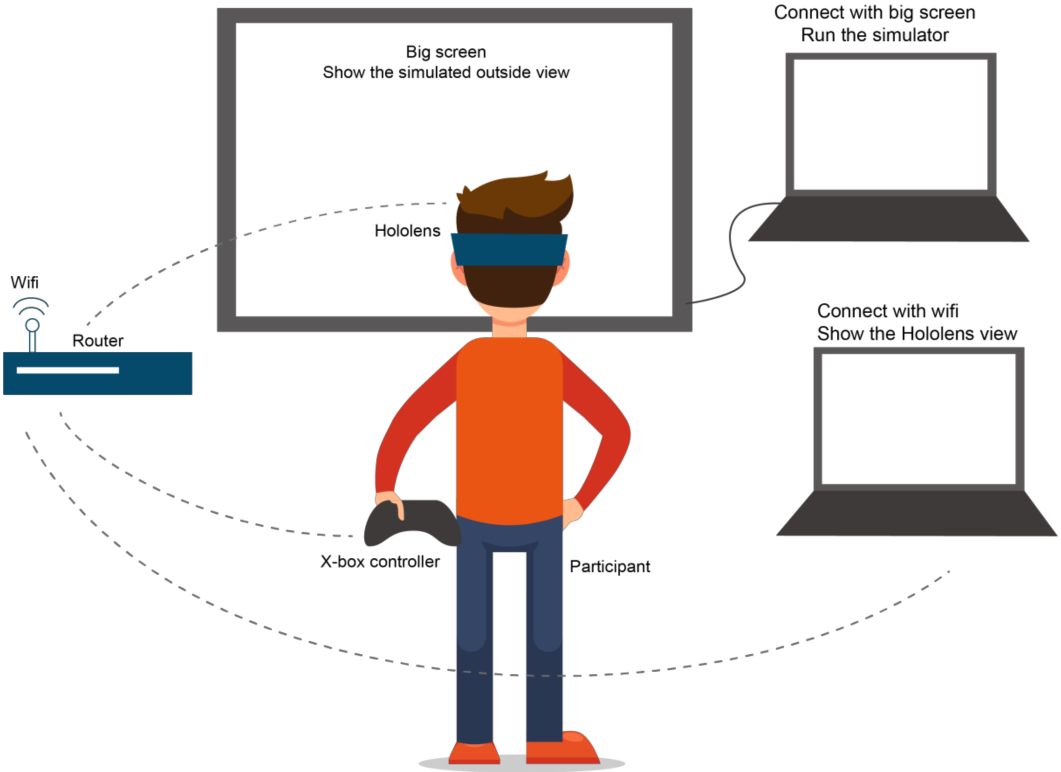


Figure 39: Test setting

Figure 39 shows the test setting. The participant wears the HoloLens and looks at a big screen (beamer, 1920×1080) showing the simulated outside view. There will be another laptop, which shows the view of the participant through the HoloLens, so that the researcher is able to understand what the participant sees. The participant would complete the dredge control task with the help of an X-box controller. Figure 40 shows the setting for testing with students in industrial design faculty of TU Delft.

Figure 40: Setting for testing with students

5.2.2. Methods

The methods used in the study are think aloud and integrated interview including questionnaires.

5.2.3. Test procedure

1.) **Introduction**
    a.) Preliminary questionnaire (age, gender, etc)
    b.) Consent form
2.) **Device Introduction (HoloLens & X-box controller)**
3.) **First Tasks: 1.1, 1.2**
    a.) Briefing for task
    b.) Participant conducts task (observe, protocol study, think aloud)
    c.) NASA TLX, QUESI (verbally)
4.) **Second Tasks: 1.3, 1.4**
    a.) Briefing for task
    b.) Participant conducts task (observe, protocol study, think aloud)
    c.) NASA TLX, QUESI (verbally)
5.) **Third Task: 1.5**
    a.) Briefing for task

b.) Participant conducts task (observe, protocol, think aloud)
c.) NASA TLX, QUESI (verbally)

6.) Interview

a.) SWRT (situation awareness questionnaire)
b.) Ask IHC employees to compare with the current system
c.) Ask for elaboration for questionnaire if needed

5.2.4. Measured data

The study compares the different perspectives and estimates, whether one can support the dredge operator better than the other in dredge control tasks. The study was focused on task performance and human experience. The participants completed five tasks. Subjective measures on questionnaire including usability, workload and situation awareness. In addition, qualitative data is gathered by observation and protocol study during testing. (All questionnaires and protocols can be found in Appendix 5)

5.3. Test results

5.3.1. Hypothesis 1

According to interviewing with 4 IHC employees, they all thought that the information delivered by HoloLens is straightforward compared with the current system. The four participants all acknowledge that the visual cues appearing near the corresponding equipment are much easier to understand. One participant calls this “a good idea”. For the first task section, all four participants can quickly understand the icons with a brief introduction. They can quickly understand the virtual tube or monitor appears when the tube is underwater. For the rest of the tasks, they can understand the icons easily and quickly. Only for the drag head distance, one participant with the first person’s perspective is not very clear about the meaning of the line and the value is not clear enough for them.

One of the employees thinks he would be used to HoloLens in a short time. He thought it was easy to understand and easy to learn. He can complete the tasks even without extra introduction of the visual cues. Another three participants have some problems with X-box controller. But they can still complete the tasks with one more trial.

All in all, the performance of four participants shows that it is easy for them to learn the meaning of the virtual information. The average value of workload for each task section with the first perspective is: 5.08, 2.67, 2.5. The average value of workload for each task section with the third perspective is: 3.42, 3.33, 2.5. Although there are only 4 participants, the measured work load is relatively low when the full score is 21.

Two participants, one with the first person’s perspective, the other one with the third person’s perspective both think HoloLens can give dredge operator more freedom. The operator does not have to always sit on the control chair any more. The operator can do the control task wherever they are on the vessel.

Therefore, Hypothesis 1 is supported by the qualitative data. It is better to complete dredge control tasks (task 1.1 to task 1.5) through HoloLens than the current system. The participants can learn quicker and need less workload.

5.3.2. Hypothesis 2

I first comparing measured data with students of the two different perspectives. For Task 1.3, 1.4, only the sub-question of NASA of frustration has an indication with $p<0.1$. The question is that “how insecure, discouraged, irritated, stressed, and annoyed were you”. Higher value means the participants feel more stressed. The boxplot graph (figure 41) shows the indication is that the participants with the third person’s perspective feel less stressed than those with the first person’s perspective.

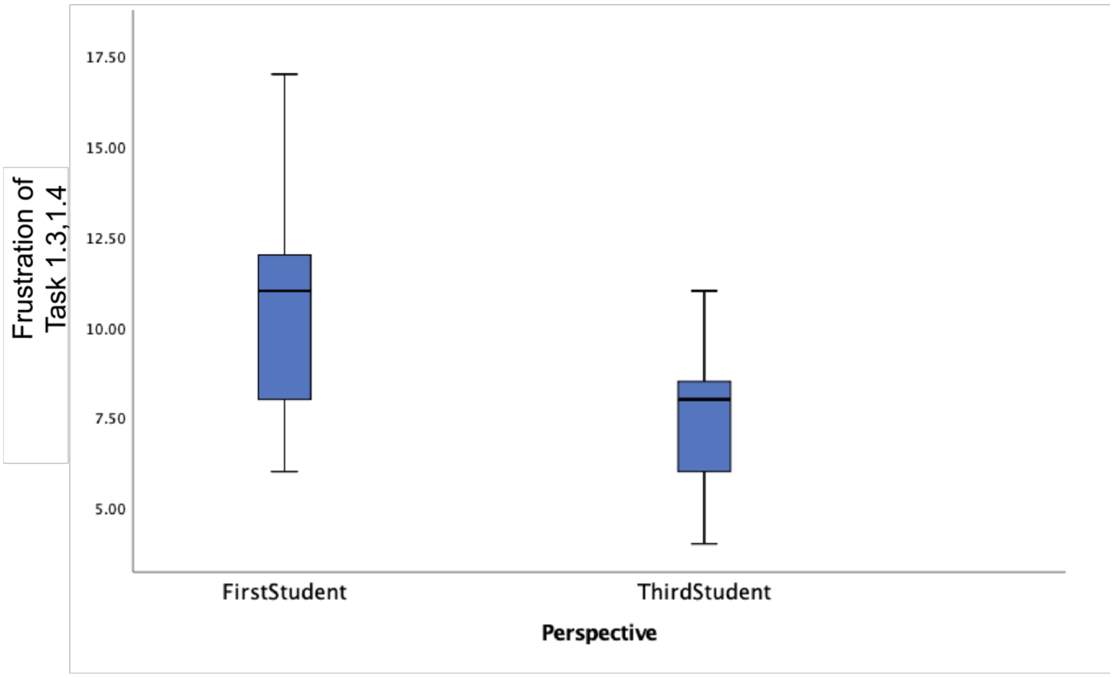


Figure 41: Boxplot graph of comparing frustration of Task 1.3,1.4

For Task 1.5, the sub-question of NASA of performance has an indication with $p<0.1$. The question is that “How successful were you in accomplishing what you were asked to do?”. High value means the participants think the performance is good. The indication is that participants with the third person’s perspective think their performance is better than those with the first perspective (Figure 42).

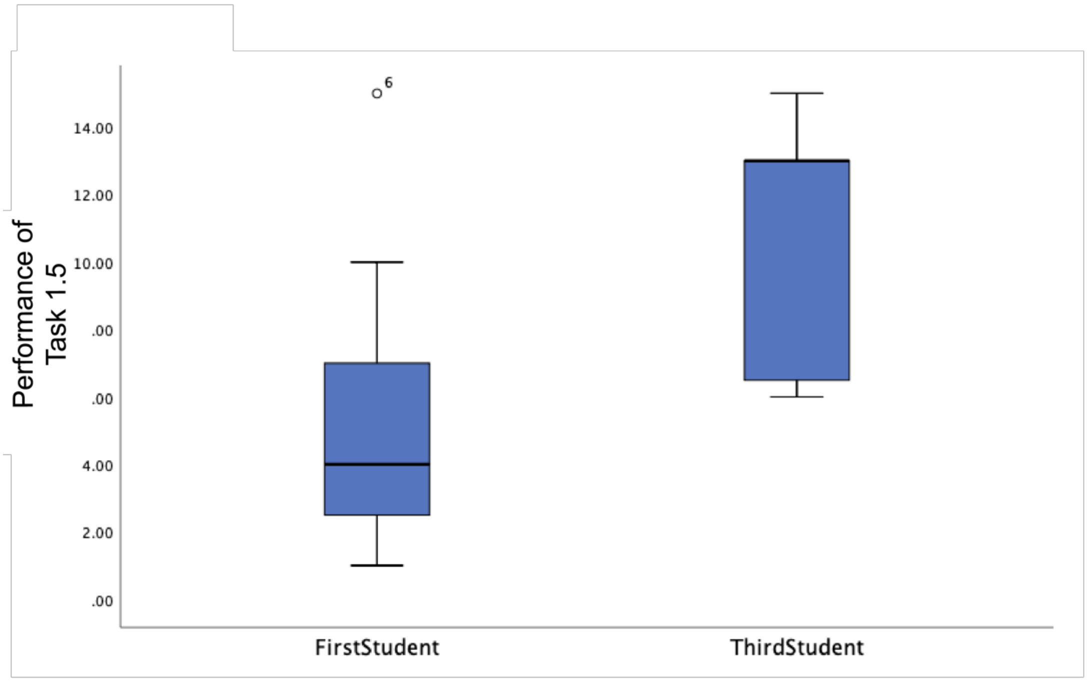


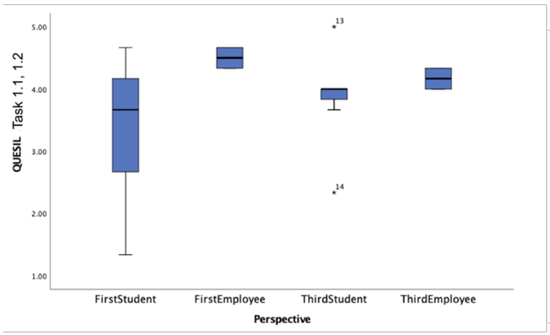
Figure 42: Boxplot graph of comparing the performance of Task 1.5

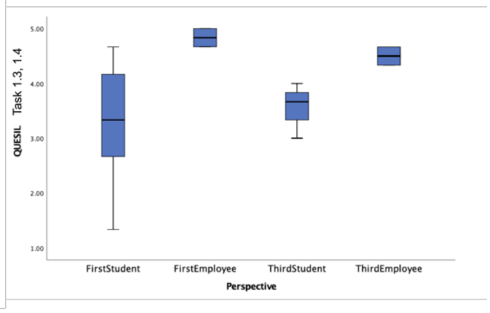
The two indications result from the different perspectives' view. The third person's perspective shows the spatial shape of the suction tube more clearly. The participants could have a clearer overview of the situation. Thus, the participants are more confident about their performance and feel less stressed.

The statistical study supports hypothesis 2. At least, participants with the third person's perspective could have a clearer overview of the situation than with the first person's perspective.

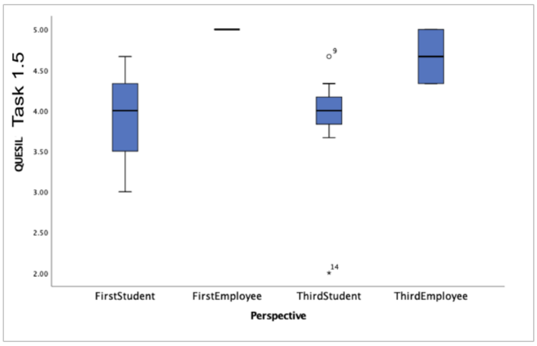
5.3.3. Other findings

Although there are no significant results, there are still interesting findings when comparing measured data of students with employees. Usability was measured by QUESI questionnaire. The questionnaire has different subfactors which conclude from different questions. The subfactor "L" means low perceived effort of learning. High value means low perceived effort of learning. The figure 43 shows the comparison of the measured data of this subfactor for all 3 task sections. The figure indicates that for all the tasks, participants who have basic dredge knowledge perceive lower effort of learning than participants without any dredge knowledge, no matter which perspective they have.





(1) (2)

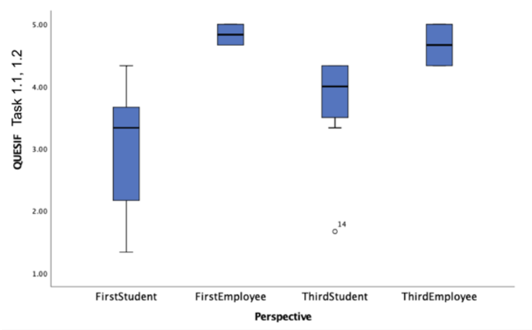


(3)

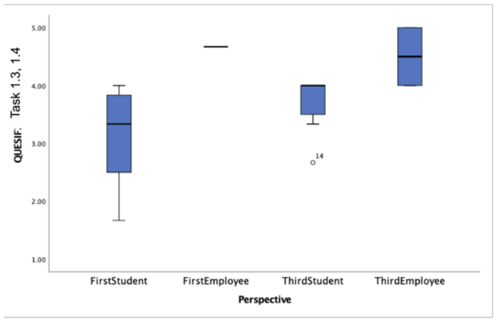
Figure 43: Boxplot graphs of QUESI-L for 3 task sections (1) Task 1.1, 1.2 (2) Task 1.3, 1.4 (3) Task 1.5

Figure 44 shows the comparison of "QUESI-F" which means "high familiarity". The figure indicates that IHC employees achieve higher familiarity than students. This may be one reason that IHC employees feel less effort of learning than students.

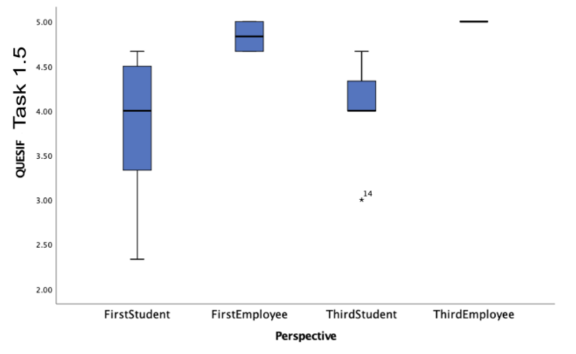
There are other qualitative data collected by observation. Most participants mention that the use of X-box control was not user-friendly. This affect their user experience a lot. But they also confirmed that once they learnt how to use it, the tasks were easy. A lot of participants also mentioned that the seabed, the distance value and the line between them were all white. It was hard to distinguish them, especially for the distance value. One participant also suggested that the arrow could have some animation effect like blinking to indicate it is still moving because the moving speed is very slow.



(1)



(2)



(3)

Figure 44: Boxplot graphs of QUESI-F for 3 task sections (1) Task 1.1, 1.2 (2) Task 1.3, 1.4 (3) Task 1.5

5.4. Conclusion

Combining the analysis above, here is the conclusion:

- Compared with the current system, HoloLens applications can give the information in a more straightforward way.
- Compared with the current system, simplified signals with its spatial property in HoloLens applications are easier to understand.
- Thus, compared with the current system, HoloLens applications require less workload.
- With the third person's perspective, operators could have a clearer overview of the situation than with the first person's perspective.
- It is easier for novice operators to learn the use of HoloLens applications than people without any dredge knowledge.

5.5. Discussion

Although all 4 IHC employees give positive feedback of the prototypes, the subject size is still small. It is difficult to do the same test with the current system as well. The data collected is not strong enough to find more added value of HoloLens. More tests with real operators are needed to find out more benefits the HoloLens could provide.

When testing, the limitations of HoloLens like its weight, its small field of view affect the user experience. But it is expected the device would be improved in the future. The HoloLens 2.0 is going to be released soon this year.

Meanwhile, the prototypes are designed according to the selected tasks. The selected tasks are extracted from a long process. When considering the selected tasks with the whole process, there will be more information the operator needs to know. For example, the vessel is always sailing so that the structure of seabed will be changed. It is important to make sure the operator understand the change of seabed. The data of the seabed surface should be checked.

5.6. Recommendation

According to the suggestions from the participants, the prototype should be improved first. The color of seabed, the line between drag head and seabed and the distance value should not be the same. The value of distance and angle should be big enough to see clearly. The arrow could have more animation like blinking to show it is working. Because the moving speed is too slow.

It is better to connect HoloLens with control chair. The use of X-box controller is not very user- friendly and has a negative effect on user experience. It is also suggested to do more tests with novice dredge operators.

The research confirms the ability of HoloLens. Further research on the rest tasks in the dredging process is needed. HoloLens can also give operators more freedom. With more research, the way of controlling may be changed as well. Dredge operators may not have to always sit on the control chair any more.

Last but not least, it is better to keep following the development of HoloLens like HoloLens 2. The device itself is still not very reliable. But it is believed that it would be improved very soon.

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