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Master's Thesis
Academic Year 2021

OpenWater: Experiencing Ocean through Haptic Method

Keio University
Graduate School of Media Design

Bohan Wang

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

Bohan Wang

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Abstract of Master's Thesis of Academic Year 2021

OpenWater: Experiencing Ocean through Haptic Method

Category: Design

Summary

The ocean covers more than 70% of the surface of our planet. It not only plays crucial role in planet ecosystem, but also become one of the most popular tourist destination. Although people are attracted by ocean, the understanding of ocean is limited. Additionally, variable sea state is potential treat for marine activities.

This research is aiming for enhancing the understanding and experiencing of ocean by haptic design. Regarding sea surface temperature and wave movement as two main factors to define haptic ocean experience, a device assembled with water tank, wave generator and temperature controller is constructed. User can choose their interested sea area around Japan to experience local sea state via putting hands into tank.

Experimental result suggests that experience shares similarity with real ocean in intermediate level. Users tend to be more impressive to temperature changing rather than artificial wave. Moreover, experiencing sea state before sea activities may reduce one's anxiety level.

Keywords:

haptic design, marine activities, coastal tourism, ocean, remote experience, wave simulation, scuba diving

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A big thanks to Bartx and Goth, my programming saviors! Without your help I cannot make my wave generated in this tiny tank. One flower is a world, one wave is an ocean.

The road leads to stars is always rough. May the ocean guide you.

Grand Blue Forever.

Chapter 1
Introduction

1.1. Background

1.1.1 Ocean and Human

Taking a general view over the earth from outer space, it is easily to discover that the surface of our planet is mainly covered by the color of oceanic blue. The ocean, which covering approximately 72% of the earth [1], represents biological diversity of the planet, drives global climate, provides 50%-80% of the oxygen which life relies on [2]. No matter if people live in coastal area or further inland, ocean always plays an important role in every earthling's life. According to The Ocean Conference held by United Nations in 2017, about 2.4 billion people, which equivalent to 40% of world population live within 100 km of the coast. Meanwhile, coastal and marine resources are essential for these people live in coastal area, both for life-sustaining and economy [3].

Although majority of global population may not live alongside seashore, coastal area has already become one of the most popular tourist destination. As demonstrated in United Nations' report, till 2017, about half of the international tourists travelled to the sea or seaside area. Additionally, tourism has massive influence to the GDP of developing island countries, approximately accounts for more than 25% of a total [3]. Ocean is vital, fertile, and charming. However, it is also one of the last unknown frontier which human have rarely explored. Only less than 20% of the ocean are explored [4]. Scientists have photographed galaxies light years away, whereas the secret of whale sharks' breeding places still remains in deep sea.

On the other hands, human's activities are also making significant influence on ocean. The excessive carbon dioxide emission has resulted in average surface temperature and sea level rising. Plastic pollution is not only affect land environment, but also terribly harming marine ecosystem [5]. Since the problem of ocean can directly impact worldwide environment, global economy and industries, government decisions, and personal lifestyle, raising the awareness and understanding of ocean of every individual could be considered as an essential issue under the global scale.

1.1.2 Recreational Marine Activities

Alongside the development of coastal tourism, population engaging in marine sports or activities are continuously increasing. For instance, according to The Diving Equipment & Marketing Association (DEMA), there are over 6 million active scuba divers and 20 million snorkelers worldwide, as well as 23 million people participate in surfing by 2019 [6]. Furthermore, surfing is planned to listed as an official Olympic competition and make its debut in 2020 Summer Olympics in Tokyo. For safety concern, marine activities more or less require understanding of sea state such as wave, swell or current condition. Moreover, the training of marine activities usually includes the ocean literacy which defined as understanding about relative influence between human and ocean. In PADI's Open Water Diver Manual, which is a textbook of entry-level course for scuba diving, basic knowledge of ocean is required to meet the standard of being certificated, meanwhile, proper awareness and attitude towards ocean environment and creatures are addressed as requirement as well [7].

Security is an inevitable issue for marine activities participators as well. For scuba divers, in 2017, there was 8,498 injuries reported to Divers Alert Network worldwide, and 228 of the total, which equal to 2.68% were fatalities [8]. Fundamental security principles are often highlighted in the very beginning of marine sports training course or introduction session.

Therefore, participating in marine activities can be considered as efficient path to understand and enjoy ocean, as well as security awareness should be raised during water activities.

1.2. Motivation

Previous researches has sited that citizens has a limited understanding of common sense of ocean and even less knowledge about marine environmental issues and protection [9]. However, the level of understanding could massively drive people's attention and impact their decisions [10]. One of the main concern of this research could be capturing citizen's interests and raising the awareness about ocean environment by cultivating people.

Secondly, as a scuba diver and free diver, it is always passionate for introducing how fascinating and vivid the underwater world is to whom have limited opportunity to explore the marine world with their own eyes and hands. However, especially during the pandemic of Covid-19 since 2020, the situation does not allow citizens to travel as free as normal. Going to the sea become much more difficult and expensive for people live in non-coastal area. For active marine activities participators, such as divers or surfers, Covid-19 also tears them up with oceans. To help people to reconnect with ocean, therefore, how to both effectively and remotely deliver the marine phenomenons is considered as another main concern of this design research.

Thirdly, although people who doing marine sports usually rely on weather and sea state broadcast, only abstract numbers sometimes may drive people to make wrong decision, which often cost time, money, or even pull them into dangerous situation. To reduce this kind of risk, how to develop more concrete method to represent sea state, also be evaluated as an important aspect in this research.

1.3. Research Goal

The research goal of this thesis is by designing haptic method allows user to experience ocean despite the geographical limitation, for developing citizen's understanding about marine phenomenon. A device associated with water tank and controller kits generated by Arduino is utilized to represent ocean by simulating instant temperature, wave and underwater current of a user-specified marine area around Japan.

1.4. Contributions

This thesis contributes to the field of haptic design and immersive virtual environment simulation, as it applies haptic method to simulate sea state. It also examined utilizing haptic design whether or not help citizens gain better understanding on unfamiliar or abstract object [11]. It is also an attempt to simulate nature wave in a limited size environment. Fieldwork, quantitative research, questionnaire and interview would be conducted in this research.

1.5. Thesis Outline

This thesis is structured as follows:

Chapter 1, as an introduction session, goes through the facts of ocean-human relation and the level of citizen understanding of ocean as research background, and gives brief introduction of main concerns of design and research goal.

In Chapter 2, related researches are discussed from the scale of multiple media representations and practical use of ocean simulation in various scenarios. Haptic designs in similar filed are examined as well, such as wind.

Chapter 3 is mainly focused on design concept based on fieldwork and interviews with sea goers, haptic design components, system logics, and procedure of prototyping. There are three attempts of prototyping introduced in this section.

Evaluating tests are discussed in Chapter 4. It includes the content about test design, result and discussion. Test based on ocean ware spectrum, in person comparative test with every prototype are conducted for verifying the validation.

Chapter 5 gives the whole research conclusion, limitation and future works are also discussed as well.

Chapter 2
Related Works

2.1. Exploring Ocean via Multimedia Content

In 2002, psychologist Mayer states that "people learn more deeply from words and pictures than from words alone" as known as the multimedia principle [12]. Nowadays, remarkable tendency of population of multimedia consumer is never decelerated. Especially during the COVID-19 pandemics, increase is accelerated by this new social distanced lifestyle. Significantly growth is observed in every media consumption field, from streaming video to TV[1]. It reflects that multimedia, is already become a main function for people accessing information. To obtain the multimedia information, respectively, people are usually using multiple senses to process. In this case, multimedia content can be defined as information which needs to be processed by multiple senses. Ocean, as a mysterious and magnificent subject, shares popularity in various media forms. Through consuming content about ocean, people is able to build understanding of ocean both directly or indirectly by using their sense.

2.1.1 Visual-Centered Content: Documentary Film

Documentary is one of the most educational media content. Meanwhile, ocean is one of the most popular subject of documentary. In Figure 2.1, collection of high rated ocean-related documentaries are listed based on data of IMDb[2]. It is filtered according to the conditions below:

1 https://www.nielsen.com/us/en/insights/article/2020/covid-19-tracking-the-impact-on-media-consumption/

2 https://www.imdb.com/

Title	Country	Release year	Runtime	IMDB rating	numbers of users rating vote	box office	Genre	Tech specifications	
The Blue Planet	UK	2001	389min	9.0	33959	-	TV mini-series		•Top rated TV shows: NO.25
Sharkwater	Canada	2006	89min	8.0	4767	$1,658,393	Film	Dolby SR	
Galápagos	UK	2006	180min	8.2	1265	-	TV mini-series	Stereo HDTV	
Océans	France	2009	104min	7.8	9009	$83,090,556	Film	Dolby Digital	
Under the Sea 3D	USA	2009	41min	7.5	1730	$55,902,624	Short film	Digital Intermediate (8K) IMAX 3-D	
South Pacific	UK/USA	2009	353min	8.7	2280	-	TV mini-series		
Planet Ocean	France	2012	94min	7.9	1404	-	Film		
Mission blue	USA	2014	95min	8.0	1577	-	Film		
Deepsea Challenge 3D	USA	2014	93min	6.8	1597	$468,070	Film	3-D HD camera	
Great Barrier Reef with David Attenborough	UK	2015	191min	8.7	1140	-	TV mini-series		
A Plastic Ocean	UK	2016	102min	8.0	2363	-	Film		
Chasing Coral	USA	2017	94min	8.1	4199	Netflix originals	Film	4K camera	
Blue Planet II	UK	2018	364min	9.3	31667	-	TV mini-series	Dolby Digital 4K camera	•The highest-rated shows of 2018 •Top rated TV shows: NO.7
My Octopus teacher	South Africa	2020	85min	8.4	10305	Netflix originals	Film		IMDB popularity rank: 359

Figure 2.1 High Rated Ocean-Related Documentary Films on IMDb.

- Popularity: vote numbers over 1000.
- Genre: belongs to documentary.
- Relevance: content is focus on marine environment/creature.

From the data of films above, it can be observed that the average rating score, 8.17, is above the average rating of IMDb. It indicates that of popular ocean-related documentaries are also produced with high quality. Secondly, visual and audio representation are tend to play considerable value on production along side the development of techniques since 21st century. Various of graphic and audio technologies employed in film making, such as Dorby Digital HD Surrounded Sound and 8K camera. Improving visual effect to restore real ocean appearance in order to provide more visually attractive experience, is the fundamental direction of development in film industry during recent years. However, it is rarely to find haptic design applied in films.

2.1.2 Interactive Content: Video Game

Ocean-themed video games can be found on various platforms from PC, PlayStation to smartphone. Visually, ocean-themed games published in 21st century are committed to rebuild 3-D virtual sea environment. Besides reproducing real environment, unrealistic components are often attached in such games. Usually, players are allow to explore the virtual underwater world, such as ABZU by Giant Squid[3], and Subnautica by Unknow Worlds[4]. Although video game provides experience in virtual world, however, it also can resonated with real world. In 2019, development company of Subnautica, hold an ocean cleanup event in order to raise players's cognition of ocean protection. Video game is already an effective function for people to recognize the ocean world. Figure 2.1 is screen shoot during game playing of Subnautica, in this first-person perspective game, players can have limited haptic experience via controller vibration.

Figure 2.2 Screen Shoot of Subnautica Game Play.

Table 2.1 Experience Survey of Aquarium in Japan

Name	**Entrance Fee**	**Educa -tional/ Research Area**	**Sea Mammals Perfor -mance**	**Sea Creature Touching Activities**	**Cinema**	**Technical/ Virtual Intera -ctions**
Osaka Aquarium Kaiyukan	¥2550	o	×	Rays, sharks in interactive area	×	×
Enoshima Aquarium	¥2500	o	o	Starfish, sea cucumber, etc	×	x
Sumida Aquarium	¥2300	o	×	×	×	×
Okinawa Churaumi Aquarium	¥1880	o	o	Starfish, sea cucumber, etc	o	×
Kamogawa Sea World	¥3000	o	o	beluga whale, dolphin, seal	×	3D CG coral reef area

2.1.3 In-situ Experience: Aquarium

Aquarium is another common place for citizens to understand and encounter sea creature and ecosystem. In survey of six aquariums in Japan (see Table 2.1), it can be found that virtual interaction supported by haptic technology is rarely applied in Japanese Aquarium. Contrarily, interaction area, which allowed visitors to touch particular sea animals, is usually highlighted as one of the most popular area

3 https://store.steampowered.com/app/384190/ABZU/

4 https://unknownworlds.com/subnautica/

in aquariums. Sea mammals performance is also popular and common, however, it is also an issue often criticized by environmentalist.

Haptic experience is employed in overseas aquarium as well. In Aquarium of the Pacific in California, USA, three-dimensional sculptures are pasted on walls, to replicate coral features and structures and are intended for visitors to touch. In its cinema, ultrasounds is used to create haptic interaction when play films[5].

2.2. Utilize Haptic Design to Enhance Experience

Employing haptic design has become a possible method to enhance user's experience in visual art exhibitions. In 2015, Tate Sensorium, an immersive display featuring on four paintings was hold in Tate Museum, London[6](See Figure 2.3). During this special exhibition, visitors can experience the painting via five senses. Mid-air haptic technology which generate vibration by ultrasonic wave, is applied to interpret artworks. The research based on this exhibition reveals that besides visual and auditory senses, touching also provides strong stimulation which significantly attributes to immersive experience [13].

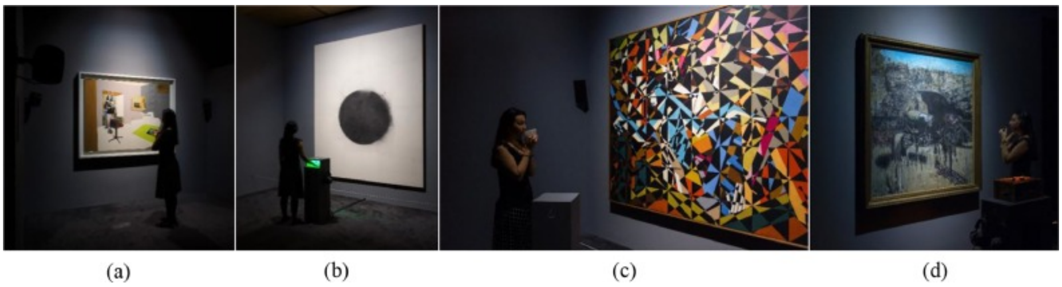

Figure 2.3 Tate Sensoriun in Tate Museum.

5 https://www.aquariumofpacific.org/exhibits/coralreefs

6 https://www.tate.org.uk/whats-on/tate-britain/exhibition/ik-prize-2015-tate-sensorium

2.3. Ocean Simulation Design as Wave Generator

Physical ocean simulation applied in marine science and marine sports also could be inspiration for haptic design of ocean experience, since it is generally take effect by generating wave, which is able to be considered as touching experience.

2.3.1 Wave Generator in Marine Science

Rossetto, Tiziana and et al.'s research in tsunami, pneumatic wave generator is used to achieve making stable, extremely long wave as tsunami [14]. Based on Wilkie and Young's tide hydraulic generator models [15] in 1950s, the tsunami generator is designed as a 4.8 m $\times$ 1.8 m $\times$ 1.15 m sealed tank, with a sealed tank installed at one side of the tank. A fan extracts air from the top of the tank, drawing water from the test flume. A valve releases air to generate a wave from the tank [14].The scale of wave shape is by controlling air value. This design is possible to simulate stable wave with long wave. If larger size tank replaced the original one, bigger tsunami is also able to be generated.

Another tsunami generator, as known as Directional Wave Basin, is located in Oregon State University. It is designed for tsunami inundation and impact. It is a 48.8m x 6.5 m x 2.1 m large basin attached with unique powerful snake-type system made of 29 boards with up to 2.1 m long stroke[7].

2.3.2 Wave Generator in Indoor Marine Sports

Wave generator technology is extensively user by Indoor surfing service such as Citywave[8] or Wave Garden[9]. People can ride on artificial wave without taking a trip to seashore and concern of weather condition. Citywave Tokyo, as shown in Figure 2.4, generates wave by several turbines. The width and strength of wave are adjustable to fit both professional and amatear surfers.

7 https://wave.oregonstate.edu/directional-wave-basin

8 https://citywave.de/fr/citywave-technology/

9 https://wavegarden.com/cove-technology/

Figure 2.4 Citywave in Oimachi, Tokyo.

Both tsunami generator and indoor surfing simulator are wave generator needs for large room to operate.

Chapter 3
Design Concept and Prototyping

Various researches have already done in the field of sea surface simulation especially in digital field. “For the design of a sea surface simulator, we need to compute the model parameters, which are the wave amplitudes, wave frequencies, and phase shifts. ” as illustrated by Naderi and Adger [16], three components usually are mainly considered in sea surface simulator design. Since there is not haptic element involved in virtual graphic design for ocean simulating, this consideration can be regarded as based on visual design concern. However, compared with visual design, haptic design is more focused on what would user experience and interaction between user and machine. Therefore, from the perspective of reproduce the ocean experience with haptic design, who could be the target user experience and which feedback would be the most impressive stimulus are major questions need to be addressed in design concept.

3.1. Target Users

Considering the research goal, which is giving people immersive ocean experience remotely, the target users can be described as citizen who interested in oceans, including coastal area tourists and active marine sports players.

In December 2020, user research is conducted in Japan, both in person and remotely. All 31 interviewees are defined as active sea goer, as visiting ocean or ocean related place at least once in 3 months.

As shown in chart Figure 3.1 and Figure 3.2, the majority, 52% of the participants are recreational scuba divers, who at least own the license of Open Water Diver. Meanwhile, 19% are coastal tourists, who usually visit seashore area but rarely do marine sports. Aquarium visitors occupied 13%, represents one lives in

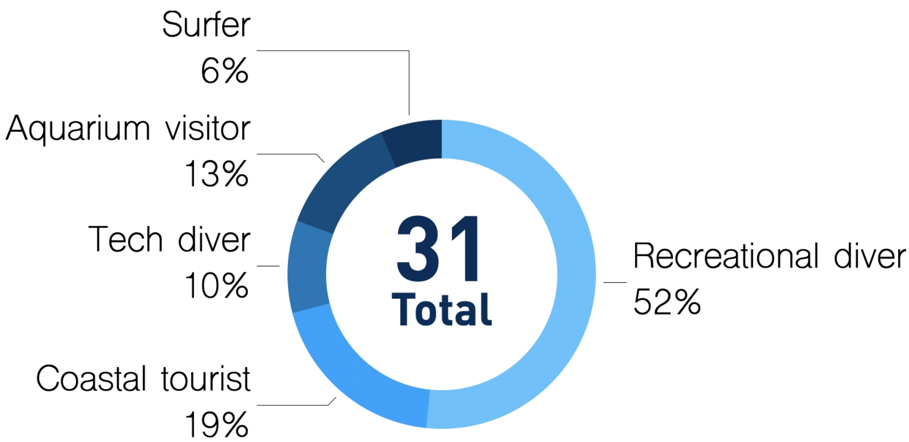

Figure 3.1 User's Profile

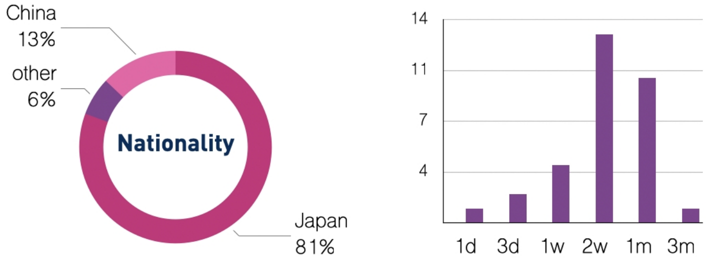

Figure 3.2 Users' Nationalities & Ocean Visiting Frequency

offshore cities but interested in ocean. There are also10% technical divers who usually considered as professional divers, and 6% surfers. Considering the cultural diversity, over 80% of participants are Japanese, whereas 13% are Chinese and 6% participants who come from various counties are also included in this user survey research. 60% of the survey are conducted offline in Izu, Okinawa and Tokyo though in person interview, and rest of 40% are remotely made via questionnaire and online interview.

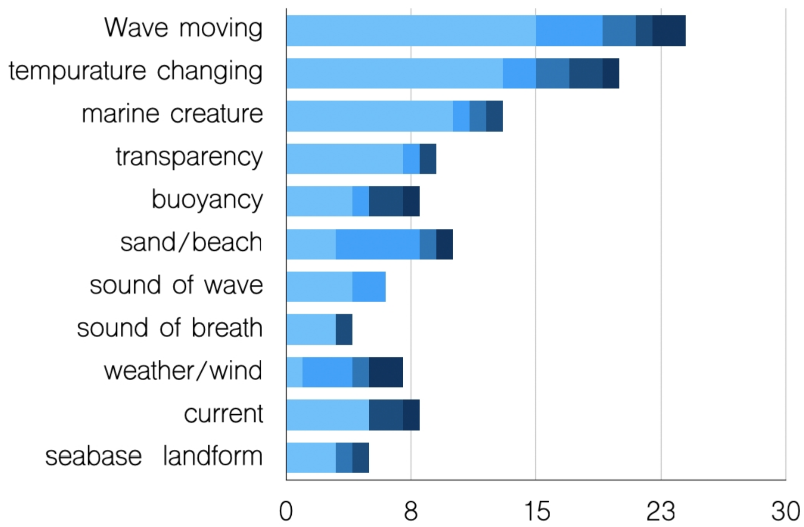

Figure 3.3 Users' Impression and Concern About Ocean

This survey aim to clarify the top impressions/concerns about ocean of active ocean goers. There are 11 aspects listed mentioned in the survey as showed in Figure 3.3, wave moving and temperature changing are significantly mentioned by participants no matter they are doing underwater sports or just aquarium visitors. Impressions of underwater sports players and people only visited beach or aquarium are also slightly different. Underwater sports players (especially divers) usually have deep impression about buoyancy which means the feelings of zero gravity, water transparency, sounds underwater and current. At the same time, non underwater sports players tend to pay more attention on the onshore factors such as weather and beach scenery. Meanwhile, both underwater sports players and non players show great interests and concern about marine creatures. Someone of diver even mentioned meeting sea creature is one of the most important reason for him to start scuba diving.

3.2. Design Logic

Table 3.1 Result Charted by Sense

Tactile	Sight	Hearing	Other
wave moving temperature changing sand/beach current weather/wind	marine creature transparency sand/beach sea base/land form	sound of wave sound of breathe	buoyancy

From the perspective of sensory, impressions of ocean can be divided into three charts as shown in Table 3.1 as well as sight, hearing and tactile sensation. Through the result of user survey, it is obvious that the top two impressive feelings about the ocean are related to sense of touch. Therefore, the haptic design needs to be generally considered as simulation of wave moving and temperature changing. On the other hand, human's tactile sensation relies on the tactile receptors under the skin, which can senses pressure, vibration, temperature, pain, etc. How to simulate the wave and temperature of ocean with pressure, vibration and thermal stimulus, is regarded as the guideline of the design logic.

The whole design is basically divided into two parts to represent wave and temperature. For the wave part, according to the previous research on sea wave and virtual graphic sea wave simulation, the sea wave model is usually considered as wave amplitude, and wave frequency. For the thermal control part, aiming for simulating the sea surface temperature (SST) around Japan, it could be a system can change the temperature from a scale of 3.12°C - 29.02°C, which is the lowest and highest SST in one year of the sea around Japan, from Northeastern part of the Sea of Japan to the sea around the Sakishima Island [17]. A control part is also applied in this system. This system could allow users to choose the interested sea area of Japan by oneself, then experience the wave, current and temperature of the chosen area. Furthermore, through adding instant databases, the goal of having remote ocean experience of ocean could be achieved, no matter where the user lives in.

3.3. Control Logic

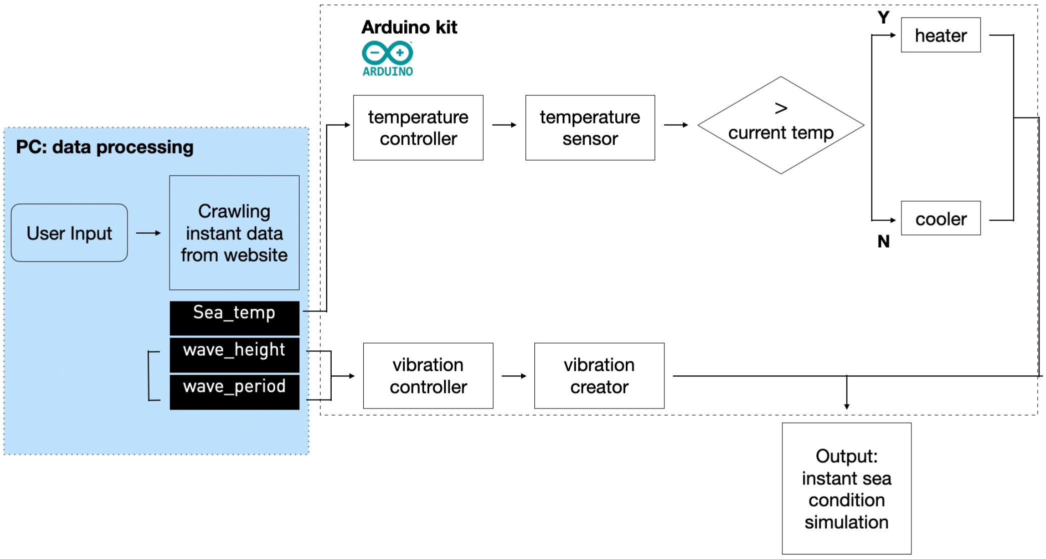

Figure 3.4 Prototype Control Logic

According to design logic, the prototype control logic is settled as the flow diagram above as well as Figure 3.4. Generally, it can be divided into three parts, input parts, processing parts and output parts.

In input part, as well as the data processing part, user is able to choose an available place. Data of places are instantly crawled from a weather broadcasting website windy.com[1] and sea temperature broadcasting website www.sea-temperature.com[2] via application programming interface(API) and data crawling. tenki.jp/wave/[3] is utilized as backup data source for wave simulation as

1 http://www.windy.com

2 http://www.sea-temperature.com/country_water/japan/122

3 https://tenki.jp/wave/

well. Three kinds of data are collected to describe two main variants, wave and SST. Natural wave is complicated because it usually generated by various causes such like wind, gravity, and current [18]. Considering the feasibility, sea wave description is usually can be simplified as wave amplitude and wave period. Hence, two kinds of data are contributed to build the wave model. wave_height(WH) is applied to reflect wave amplitude, meanwhile, wave_period(WP) is the time between two wave peaks across the same point, which represent the wave frequency. sea_temp(ST) is a variant to describe SST.

The whole processing part which shown as the part circled by dotted line in Figure 3.4, is composed with two components, temperature controller and vibration controller. In temperature control part, signal of ST is captured and compared with the current temperature(CT) with measure by a thermometer. Temperature sensor processes the temperature difference between ST and CT. If ST is higher than CT, the heater will generate till CT reached the very value of ST. On the other hand, if ST is lower than CT, cooler will be activated to lower the CT until equal to ST. The vibration controller generate the wave according to WH and WP via vibration creator.Detailed control logic of wave generator will be discussed in prototyping introduction section. All processing part is generated by Arduino Uno R3 board.

The output part is the mechanical component to generate the ocean simulation. It provides the direct haptic experience to users.

3.4. Prototype Design

3.4.1 First Prototype: Vibration Centered Prototype on Electronic Services

The first prototype is mainly focused on generating sea wave through vibration, weighting the convenience of access, electronic device becomes the first attempt. There are two ideas about prototyping as shown below in Figure 3.5.

The first idea is to attach sensor and motor which can generate vibration to user's finger. There may be various pictures of different sea area for user to choose, if user choosing and touching the picture with the finger attached with prototype,

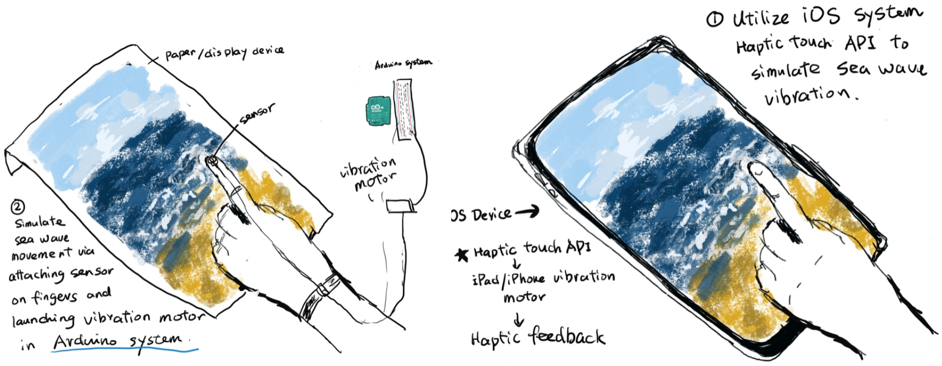

Figure 3.5 Two Ideas of Prototype Displayed on Electronic Devices

vibration will be generated by motor to simulate the sea wave. It would be a small and portable device, however, limitations are obvious as well:

- Temperature changing is hard to deliver. If a heater or cooler attached on this device, it could be closely next to user's finger, which raise the dangerous of harming user's skin.
- It is difficult to simulate the textile of water.From the perspective of user experience, without textile, motor generated vibration is difficult to simulate the pushing and pulling force of natural sea wave.
- It is hardly to reflect the instant sea state due to the input session is still relied on sense of sight: user needs to choose a picture to determine the destination of experience, but a picture is still a visual object.

The second idea is developing the prototype on Apple devices via iOS Haptic Touch API.Without relying on extra device, user may experience the ocean with one's own device – iPhone or iPad. However, similar drawbacks are unavoidable in this solution as well:

- Temperature changing is almost unable to implement with screen of Apple device.
- It is impossible to simulate water textile with screen. Without visual assistance, vibration is hardly to be associated with sea wave.

To sum up, using electronic devices to simulate sea wave through vibration is hardly to meet the goal. Besides the temperature, likewise, textile of water could also be a crucial component in haptic remote ocean experience design.

3.4.2 Second Prototype: Water Tank with Wave Generator

Regarding the importance of textile, using water directly has become a possible option for prototyping. The second prototype is generally focused on achieving wave generator part, as a result, temperature controller part does not attach in this prototype. In general, the prototype is designed as an acrylic tank fill with water, providing use a real touching water experience. Other control parts are planned to be able to attach on the tank as modular accessories.

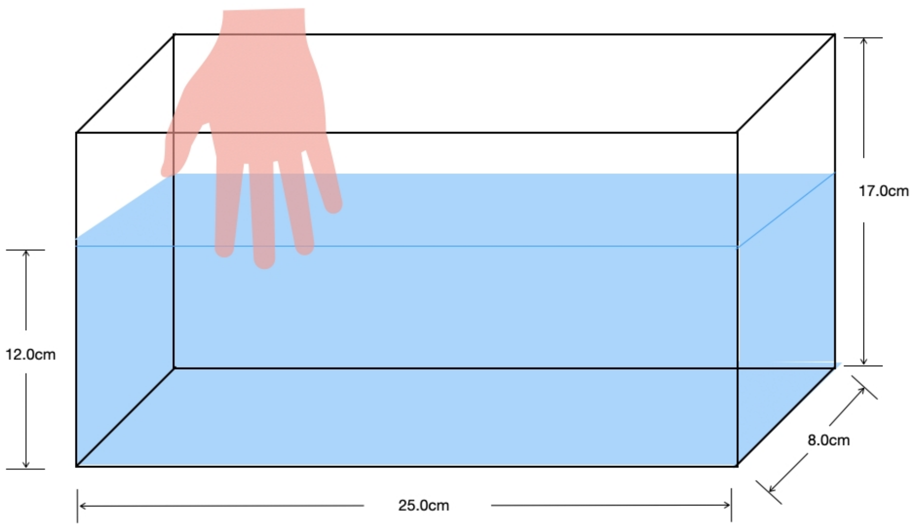

Figure 3.6 Prototype Two: Acrylic Tank

According to Figure 3.6, the tank is a cuboid without cover, aim to let user put their hand in through the top. The length, width and the height of tank is 25.0cm, 8.0cm and 17.0cm respectively. When active the whole system, 2400ml water will be poured into the tank, with the depth of 12.0cm.

Wave Generator

Wave generator module is more precisely applied in Prototype 2 as shown in Figure 3.7 . An AC Power with voltage transformer which can shift the voltage from 3V to 15V is applied in this module, with the purpose of generating waves with different amplitude. According to Douglas Sea Scale[4], which use to estimate the roughness of ocean wave for marine activities, the roughness of wave can be divided into 9 degrees by wave height. When wave height is lower than 3 meters(including degree 0-4), the wave is supposed to be gentle. If wave height is in the range of 3m to 6m (including degree 5-6), sea surface condition can be described from moderate to very rough level.Respectively, if wave height is higher than 6m, the wave would be significant rough and not suitable for any amateur marine activities. With this concern, we define three different wave levels in the module:

- Mild: when WH is less than 3, 3V voltage would apply.
- Medium: when WH is addressed in the range of 3-6, 7.5V voltage would apply.
- Strong: when WH is over 6, 12V voltage would apply (Because if turns to 15V,the maximum voltage, large amount of water will be pumped out of the container, 12V is decided to apply in this case).

The Pulse Width Modulation(PWM) signal and electric relay is applied to switch the voltage according to WH.

The whole procedure of wave generator is work as the description blow. Data of WH and WP is captured from website, then transmitted to the Arduino board via Wi-Fi module(ESP8266). Applied voltage depends on value of WH, then generate the water pump to simulate wave. At the same time, frequency is determined by the value of WP. The power is turned on once in during one wave period. Whole module is connected with laptop via USB.

4 `http://www.eurometeo.com/english/read/doc_douglas`

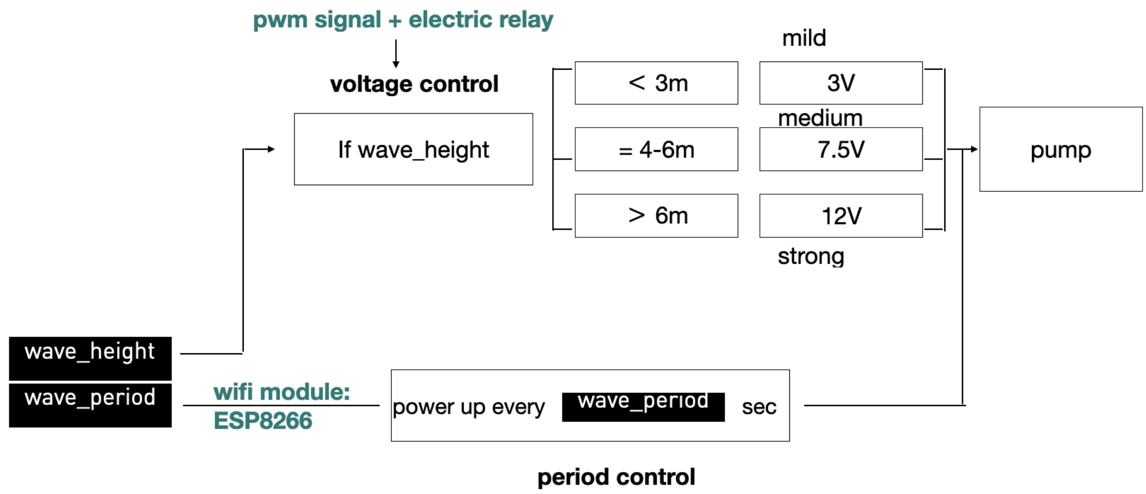

Figure 3.7 Control Logic of Wave Generator Module

Pump shown in Figure 3.8 is the main wave generator in prototype 2. It is a 15V,19W JOVTOP JT-510 pump, which has Qmax of 500L/hour and Hmax of 900cm.

Prototype Operation

Figure 3.9 shows how prototype 2 assembled and functioned. In order to create waves on surface, the pump is settled with holder, which helps to pump water with 45° angle. A Gopro camera is placed on the top of the wave generator module to record the wave, so as to make wave spectrum used to compare with real ocean wave spectrum.

In Figure 3.10, four states of wave and the differences in Crest height can be seen. In mild wave mode, the generated wave amplitude is approximately 1.3cm. In medium wave mode, 3.5cm height wave is made by pump. The maximum height of wave is about 5.0cm when strong wave mode is turned on.

Validity

Verifying to what extend the generated wave can represent the natural sea wave is the main purpose of this session. There are two methods to testify the result

Figure 3.8 Pump in Prototype 2

both objectively and practically:

- Wave spectrum comparison based on real-time wave spectrum and ISSC spectrum formula.
- User test employed Likert scale questionnaire, which is discussed in Chapter 4.

In wave spectrum comparison, graph of generated wave is captured by camera. One GoPro is placed on the top of wave generator module, and another one is placed parallel to the tank's long side, used for recording the wave from the side view. Taking the no wave surface level as the x-axis, the position of wave crest(PWC) is recorded by every 0.5 second. after coupled data of PWC recorded from two different angle, the average data is applied to draw the final graph.

ISSC wave spectrum, which also known as Bretschneider or modified Pierson-Moskowitz spectrum, is also used as one of the comparison reference, which is usually used to predict and simulate wave spectrum generated by wind. It is widely applied in both virtual graphic sea wave modeling and sea state broadcasting. The main parameters in this model are frequency and wave height, which can meet

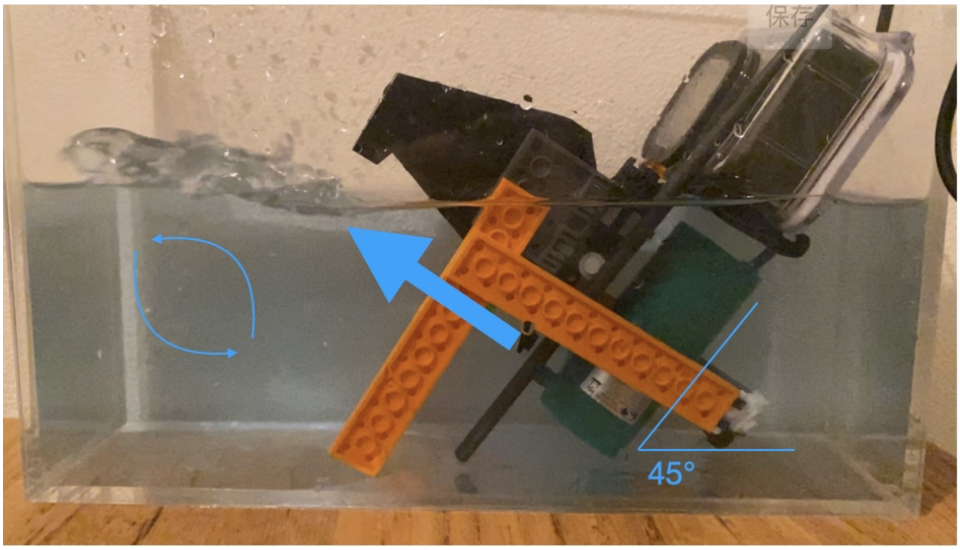

Figure 3.9 Picture of Prototype 2

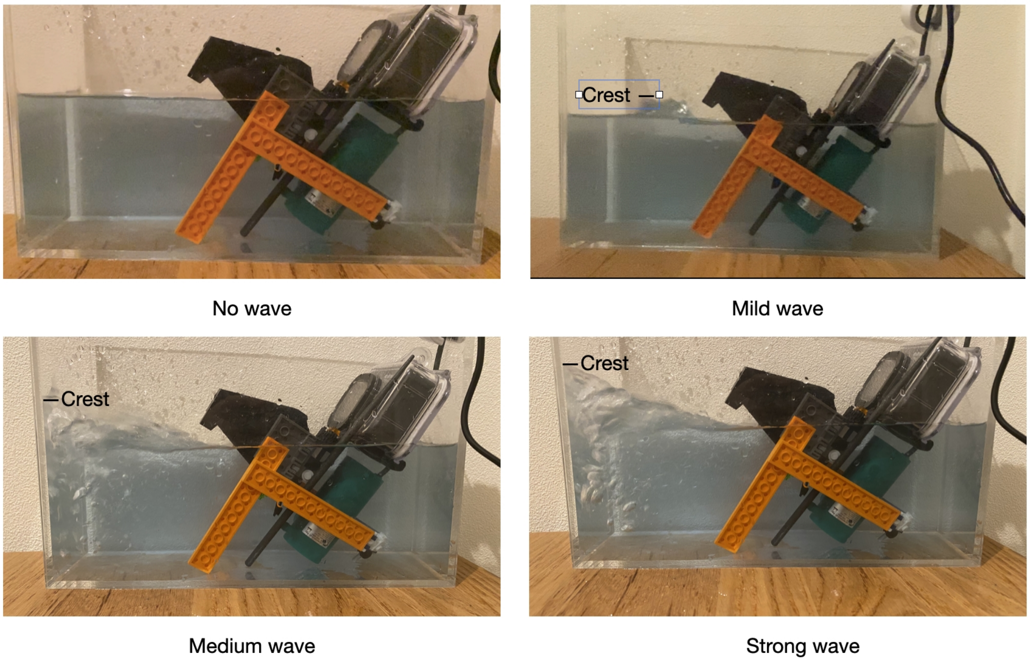

Figure 3.10 Four Wave States Generated by Prototype 2

the variants used in this research. Therefore, it is involved as a wave spectrum reference. It is defined as [19]:

$$S(f) \quad = \quad \frac{5}{16} H_{\mathrm{s}}^2 f_{\mathrm{m}}^4 f^{-5} \exp\left[-\frac{5}{4}\left(\frac{f}{f_{\mathrm{m}}}\right)^{-4}\right] \tag{3.1}$$

where f is frequency. f_{m} the peak frequency and the significant wave height H_{s} are other two parameters need to be settled.

By running the open source MATLAB code written by amarnathajay[5],a wave spectrum is drawn as below in Figure 3.11. It shows a simulated mild sea state with $H_{\mathrm{s}} = 3$m and $f_{\mathrm{m}} = 0.15$Hertz, as well as 1 rad/s.

With the similar condition, we set the WH = 3m and WP = 7s, through the method introduced above with cameras, the real time wave spectrum of Prototype 2 is drawn as Figure 3.12. Because the length of tank is not long enough to let entire wave go through, the whole wave spectrum has not been achieve to record.

Applying the value of WH and WP into H_{s} and f_{m} , the wave spectrum in same dimensions can be created as Figure 3.13.

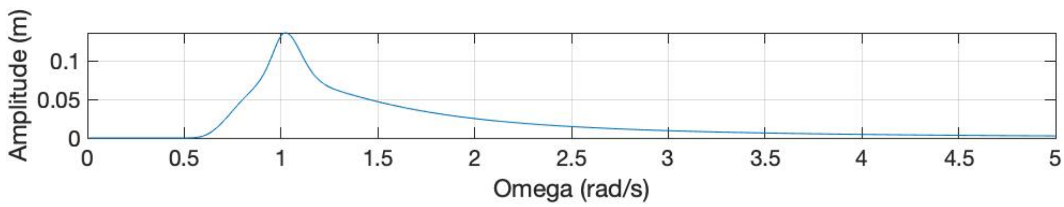

Figure 3.11 Wave Spectrum Simulated by ISSC Formula

Besides the virtual wave spectrum, real ocean wave is also recorded with the similar condition as applied in prototype wave record test as above. Moreover, considering both the land form and sea state, we conducted the real sea wave recording test in Hachijo island, in June, 9th, 2021. According to windy.com, the WH is 1-1.5m with swell, and WP is 5-10s, as a mild wave day.

The real wave spectrum is recorded in Natsumado, a place has virtical place and average depth of 8m near the offshore area. The cliff can be seen in Figure 3.14. GoPro with weight which avoiding swing is settled on the rope witch also can be found in the higher area of Figure 3.14.Camera lens is half underwater and half

5 `https://github.com/amarnathajay/SeaSpectra`

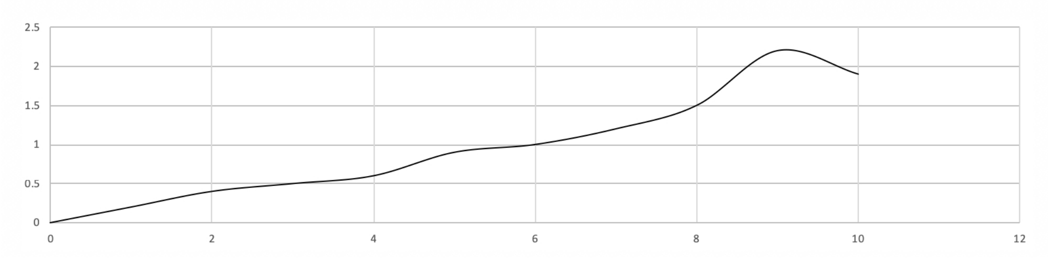

Figure 3.12 Wave Generated by Prototype 2. X-axis defines time in second. Y-axis defines wave height in 10^{-2} m.

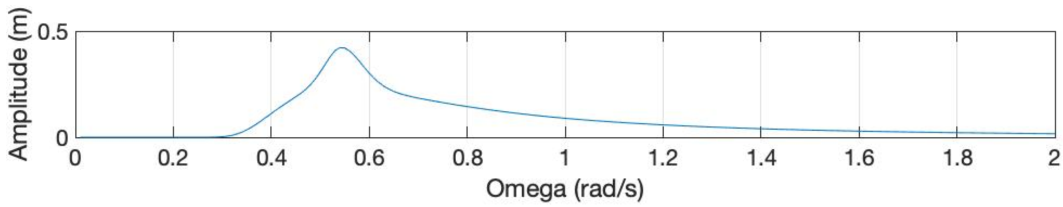

Figure 3.13 ISSC Wave Spectrum Generated by Prototype 2.

above the surface, 5 minutes video is taken, from the most stable cut, the position of wave crest is collected by every 0.5 seconds.

Figure 3.15 shows the final spectrum1 according to the data collected in Hachijo Island.

Compare Figure 3.13 with Figure 3.11, the similar shape of wave spectrum is easily to observe in both graphs. Although the frequency slightly shows differences, the energy, in other words, the force delivered by wave can be successfully achieved the goal of simulating real wave movement via the wave generated by prototype 2.It means that if user put hand in prototype, force of wave can stimulate the tactile cell on users hand in a similar level as the real wave. Theoretically, is it possible to provide a tangible experience of real wave for users.

However, if take a look at Figure 3.12 and Figure 3.15 respectively, it is obvious that the wave in real condition is more complicated rather than the wave generated by prototype. Because of impact of tide, swell, current and natural land form, as Kinsman points out in 1984 [20], double peak in one wave period is often observed on natural sea surface. This phenomenon also appears in Figure 3.15. In 3 second and 10 second, a weaker peak can be seen in the graph. However, there

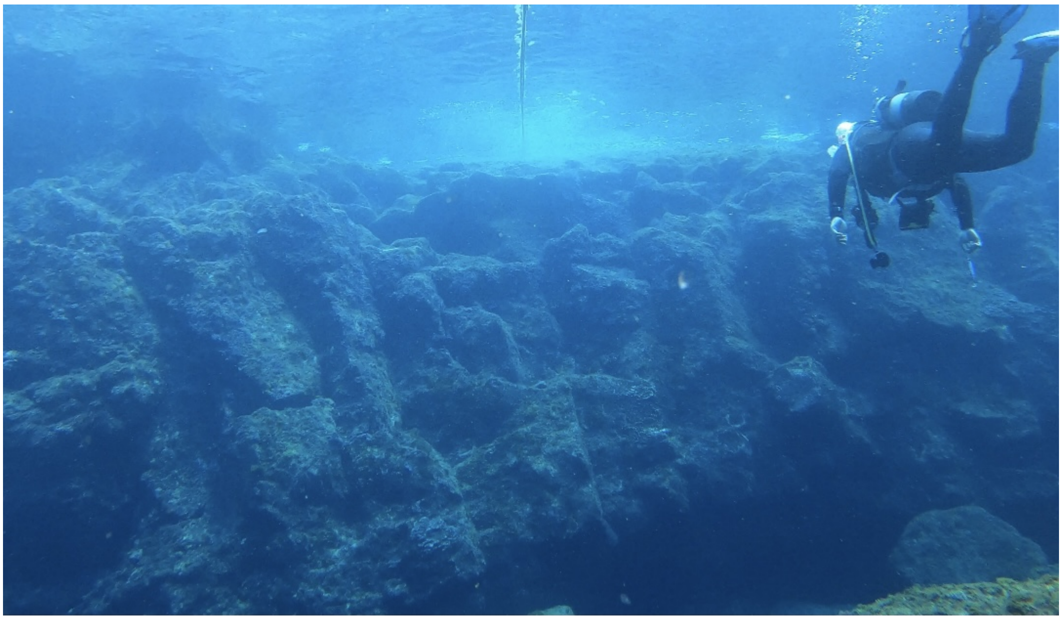

Figure 3.14 Photo of Offshore Land Form of Natsumado, Hachijo Island.

is no double peak wave in Figure 3.12. In addition, under the similar condition, natural wave seems stronger than generated wave if compare the wave height. The highest peak of natural wave is 4.8cm, while the generated wave is 2.2 cm. Necessity of adjusting strength of wave will be discuss in Chapter 4 via user test.

In summary, compared with natural wave and ISSC wave spectrum, both limitation and achievement of prototype 2 is illustrated as below:

- Prototype 2 is possible to generate wave with similar power as well as real

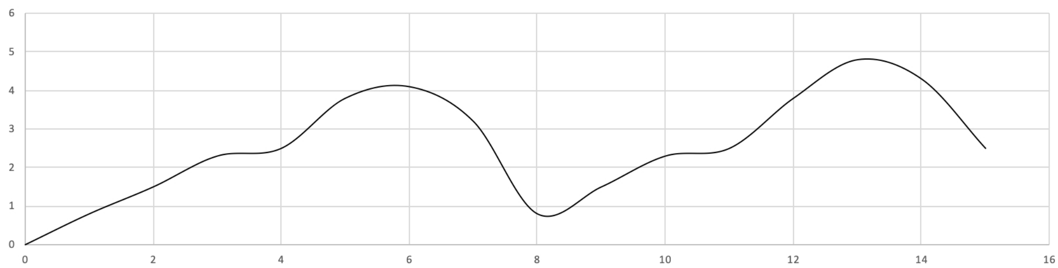

Figure 3.15 Recorded Real Wave Spectrum. X-axis defines time in second. Y-axis defines wave height in 10^{-2} m.

wave.Pump wave generator is practicable.

- There is still apparent discrepancy from the perspective of real wave shape. If it would affect user's haptic experience, and if yes, to what extend it will affect will be evaluate after user test.
- The tank's size is too small. A larger tank with longer length and higher height is necessary.

3.4.3 Prototype 3: OpenWater with Wave and Temperature Modules

The improvement of design in Prototype 3 is principally engaged in three aspects:

- Tank size adjustment.
- Wave generator module improvement.
- Temperature control module attachment.

Since the concept of design is to let user experience ocean through their own hand and body, this design is suppose to be a gate for knowing ocean. Thus, prototype 3 is named as OpenWater. Control logic of prototype OpenWater follows the diagram of Figure 3.4.

Tank Size Adjustment

The length, width and the height of new tank is 60.0cm, 10.0cm and 15.0cm respectively(see Figure 3.16).it is also build with acrylic board. The size comparison with tank of Prototype 2 can be seen in Figure 3.17. As well as considering comfort width to put one hand in, and safe height to avoid water spill over, the length is extended over 2 times longer than prototype 2 to make whole wave successfully run through the tank.

Figure 3.18 shows that continuous, whole wave can be generated in this longer tank. Validity will be discussed in Chapter 4 through user test and survey.

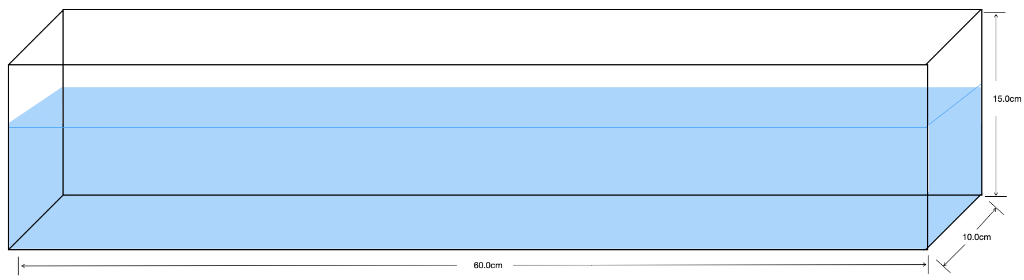

Figure 3.16 Size of Tank Utilized in Prototype OpenWater.

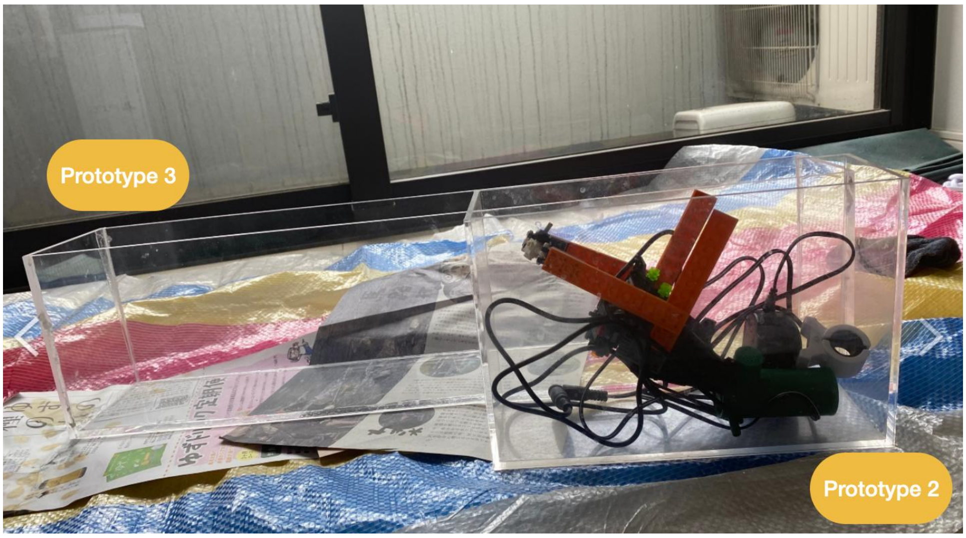

Figure 3.17 Size Comparison of Prototype 2 & Prototype OpenWater.

Wave Generator Module

Flap wave generator is applied in this Prototype. According to the later user test, flap wave generator has performed better than pump generator. Figure 3.19 introduces the operating principle of flat wave generator. Briefly, a stick is connected with 6v-9v DC motor and one 15x11cm acrylic board as drive link. If the motor is started, flat board can swing back and forth to make wave. By controlling the voltage, levels of wave height can be changed. Figure 3.20 shows a picture of flap wave generator attached on the tank. Wave made by this generator can be seen

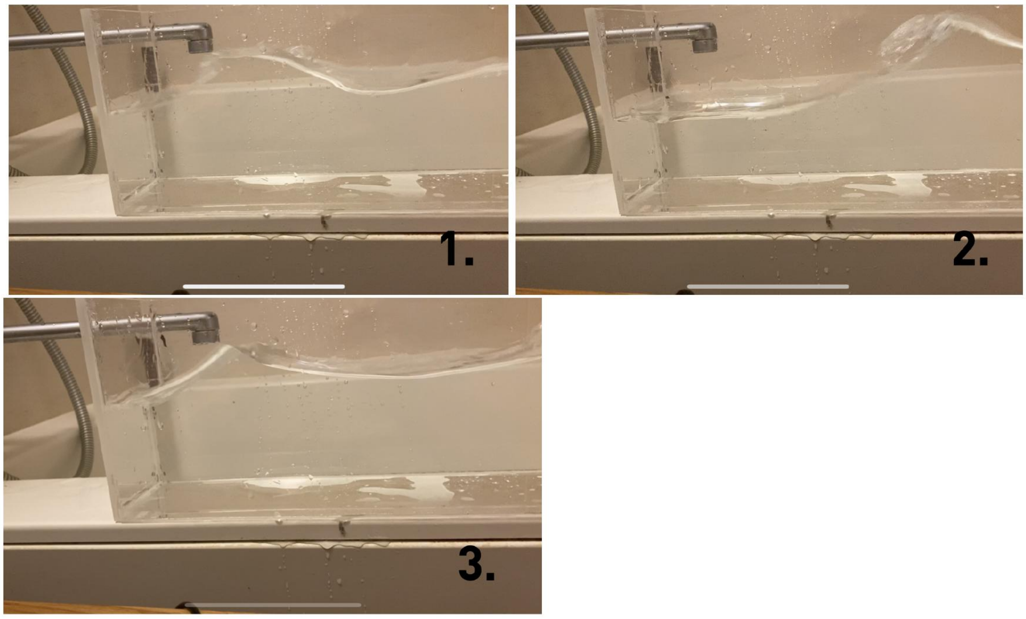

Figure 3.18 Continuous Wave in Prototype OpenWater.

in Figure 3.18.

Temperature Control Module

Temperature control module can be separated into two parts, as well as heater and cooler system.

Regarding the safety of underwater working environment, heater part employs 160W aquarium heater, which can work in 15°C-35°C environment (See Figure 3.21). It is horizontally settled at the bottom of tank in order to let heater be completely immersed in water(See Figure 3.22).

Cooler system is assembled hydrocooling system, which including CPU fan (Cooler Master FN1179 RR-H412-20PK-R2), 2 semiconductor cooling piece (TEC1-12706), water cooling block, pipe and water pump which also used in prototype 2 as wave maker. The whole system can safely and stably operate under rated voltage 12V, in temperature range from -30°C to 83°C. Pump continuously pumps water into the core cooler device, assembled with CPU fan and semiconductor cooling pieces as shown in Figure 3.23, water temperature will be lowered, then

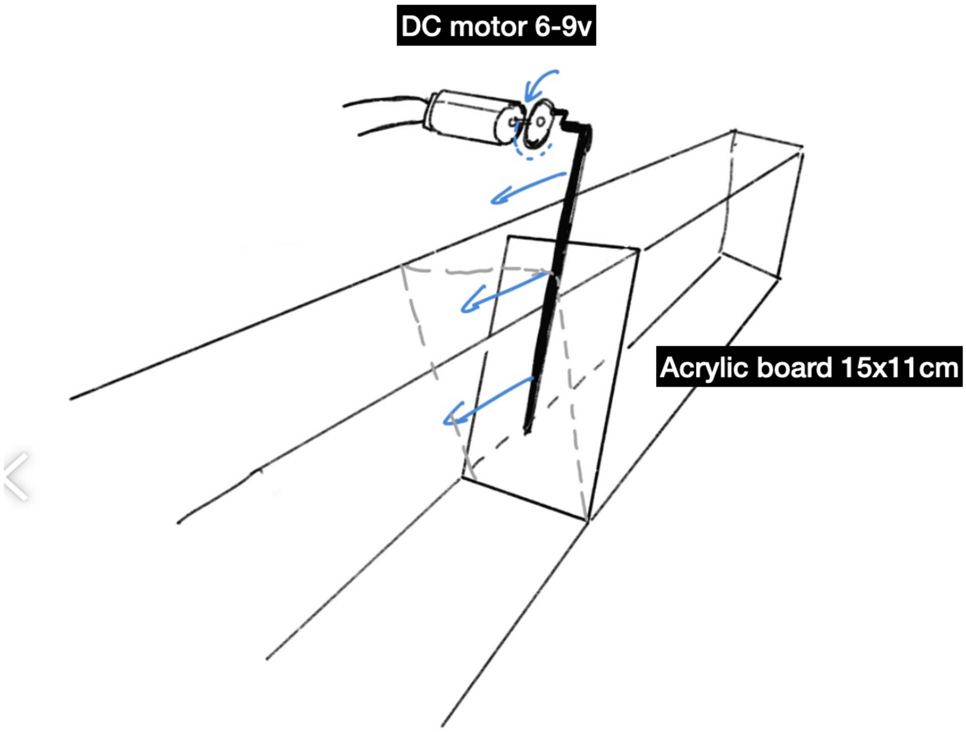

Figure 3.19 Introduction Sketch of Flat Wave Generator.

flow back to tank. This circulation is not stopped until reached target temperature.

Thermometer is attached to the temperature control module as well.

Whole Prototype

Figure 3.24 shows the photo of prototype with every module attached. Every module can work independently in this prototype. Thus, when user experience the prototype, pipes of cooler system can be removed from tank to let wave moves more smoothly. At the same time, due to the minimum work temperature for heater is 15°C, when target temperature is lower than 15°C, it will be considered as invalid data and asked for another attempt to choose target place.

The evaluation and discuss of prototype OpenWater is conducted in next Chap-

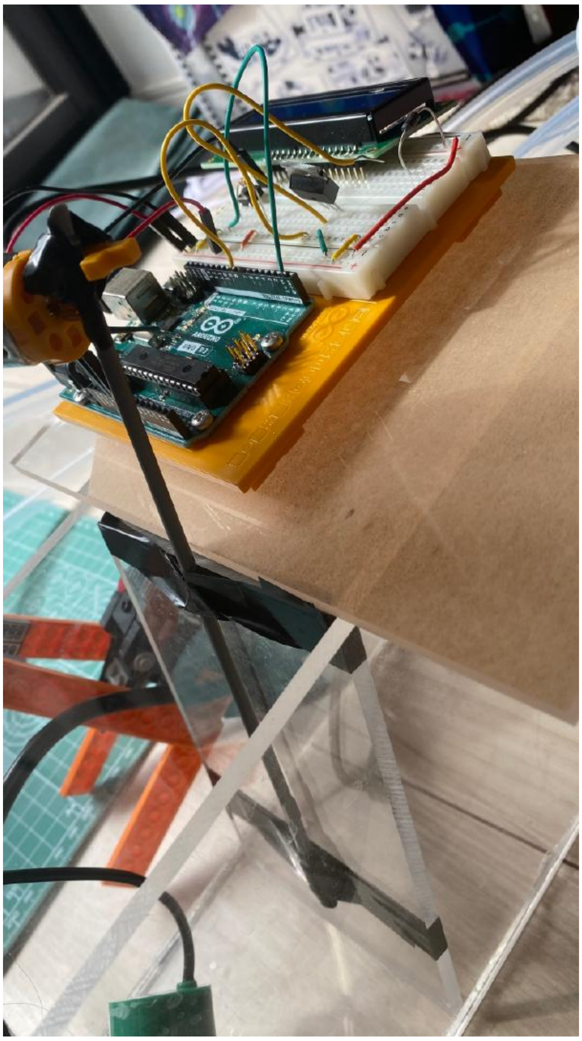

Figure 3.20 Photo of Flap Wave Generator.

ter via multiple user researches.

Figure 3.21 Gex Heater for Aquarium Tank.

Figure 3.22 Photo of Heater.

Figure 3.23 Photo of Cooler System.

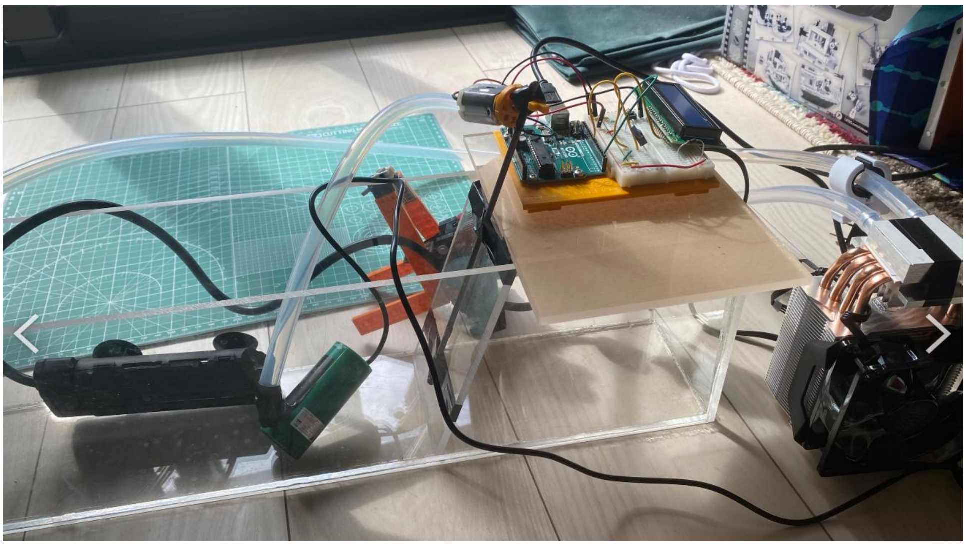

Figure 3.24 Picture of All Components of Prototype OpenWater.

Chapter 4
Proof of Concept

After the theoretical test by using ISST wave spectrum and recorded wave graph, feasibility of the prototype is proved. However, from the practical perspective, the user research is still need to be done. In this chapter, user research via Likert scale questionnaire, field work interview, quantitative correlation studies conducted in various area with different sea state are illustrated and analyzed.

4.1. Evaluation User Test for Prototype 2

4.1.1 Test Purpose

This user test is aiming for evaluating issues below:

- Practical feasibility. If and to what extend the design can meet user expectation to ocean experience.
- Correlation between ocean visiting frequency and degree of satisfaction of prototype.
- Collect users' feedback to improve prototype.

4.1.2 Test Participants

Test participants are randomly sampled from citizens live in Japan, with an age range from 20s to 40s. It is supposed to have 10 people participating in this test, however, due to the State of Emergency of Tokyo and other 9 prefectures in May and June 2021, 7 people actually took part in the test. All participants did the test individually and separately.

4.1.3 Method

Table 4.1 Questionnaire of Prototype User Test

	Circle the correct numeric response to each question	
	Question	**Survey Scale:** **1=Strongly Disagree** **2=Disagree** **3=Neutral** **4=Agree** **5=Strongly Agree**
1	Trip to ocean/aquarium is always enjoyable.	**1 2 3 4 5**
2	I do not think ocean is horrible.	**1 2 3 4 5**
3	In my leisure time, I tend to go to ocean/aquarium.	**1 2 3 4 5**
4	I usually enter the sea if it is possible.	**1 2 3 4 5**
5	I can associate the feeling with ocean with I try this prototype.	**1 2 3 4 5**
6	The wave frequency is similar to real ocean wave.	**1 2 3 4 5**
7	The textile of wave I experienced in prototype is similar to real ocean.	**1 2 3 4 5**
8	There are rarely difference between my hands' feeling of prototype and real ocean when the wave rush to my hand.	**1 2 3 4 5**
9	The experience of trying prototype can successfully provide me impression of the particular sea state of the chosen place.	**1 2 3 4 5**
10	If I close my eyes while experience the prototype, it can provide stronger impression and association about real ocean.	**1 2 3 4 5**
11	If I close my eyes and listen to the wave sound while experience the prototype, it can provide stronger impression and association about real ocean.	**1 2 3 4 5**

Firstly, participants are asked to input a ocean area they last visited. After prototype is active, they will put one of their hands into tank and experience wave movement approximately 1 minute (maximum 2m). Then participants would have a short break. Afterwards, they are asked to try the prototype again with eyes close. The last step is experiencing the prototype with eyes close and earphones. A cut of wave sound which recorded in Yuigahama, Kamakura will be played during prototype experience. A Likert scale questionnaire (see Table 4.1) needs to be filled after whole prototype experience. Short interview is also conducted to inquire participant's feedback. All parts of prototype are completely cleaned and disinfected with alcohol before every participation.

Reliability

Scale: ALL VARIABLES

Case Processing Summary

		N	%
Cases	Valid	7	87.5
	Excluded[a]	1	12.5
	Total	8	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.666	11

Rotated Component Matrix[a]

	Component 1	2
Q1	.931	
Q3	.850	−.452
Q2	.794	−.525
Q4	.717	−.569
Q5	−.633	
Q8		.948
Q9		.881
Q6	−.604	.745

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

Figure 4.1 Reliability Statistics and Factor Analysis of Table 4.1

According to the data collected from 7 participants, reliability and validity test is done via SPSS Statistics (see Figure 4.1). As a result, the Cronbach's Alpha of this questionnaire is about 0.7, which indicates the questions in test is reasonably designed. Besides Q10 and Q11 which related to user experience without sight and with auditory, the factor analysis reveals there are 2 components in this questionnaire. Q1, Q2, Q3, and Q4 can be considered as one component represents the tendency of interest and familiarity of ocean. Simultaneously, Q5, Q6, Q8, and Q9 indicates the degree of satisfaction of prototype. Q7 is regraded as invalid question in factor analysis.

4.1.4 Result & Analysis

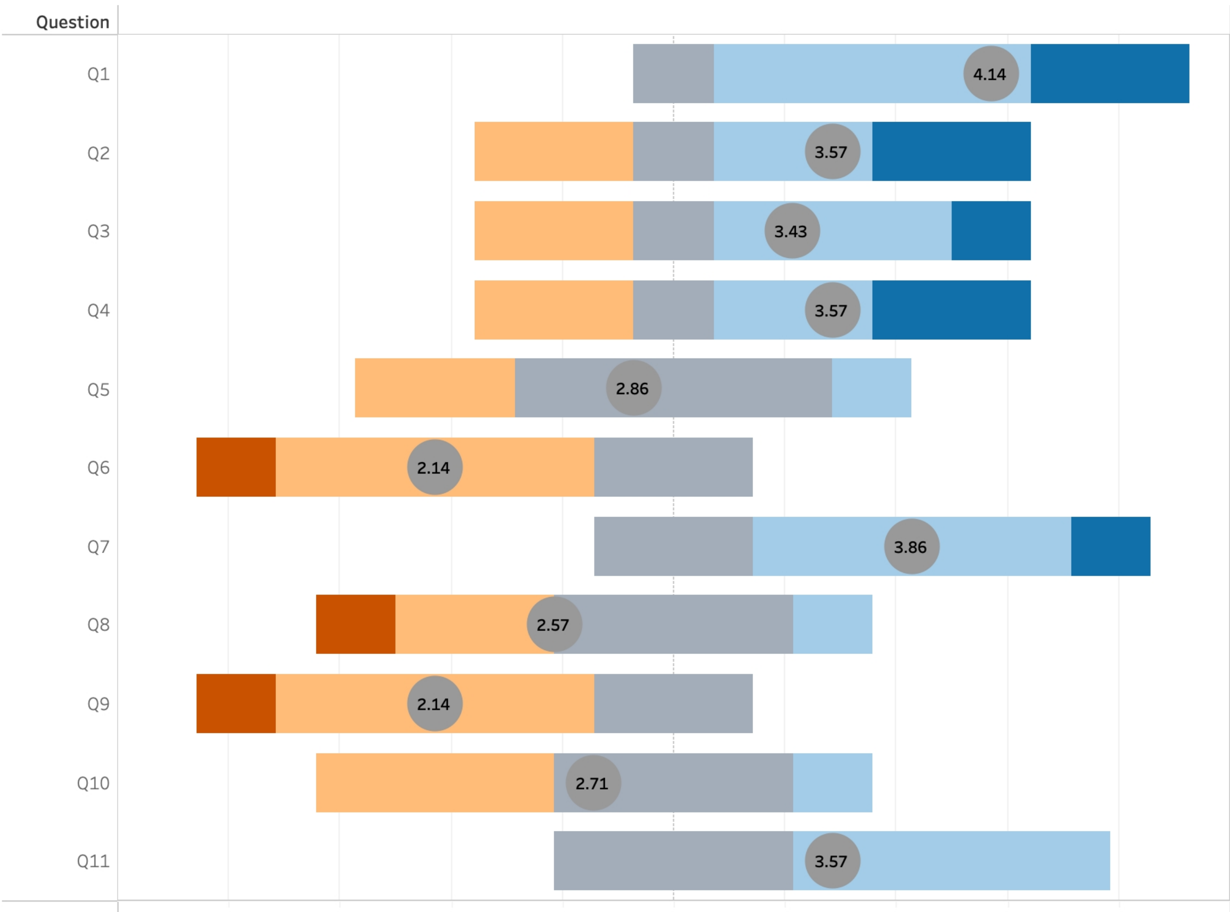

Figure 4.2 Result of Questionnaire

Figure 4.2 shows the detailed result of user test on prototype 2. From this chart, it is clear that all participants tend to have interest in ocean, and strong willing to visit coastal area. Nevertheless, besides the texture, the performance of prototype is not able to achieve the average expectation. Wave frequency and immediacy which represented by instant sea state could not serve the real ocean experience on a reliable level. Comparatively, wave movement simulation performed better in the test. Result related to visual and auditory sense indicates remarkable consequence as well. Without sight seems not to have heavy impact on user experience. On the other hand, listening to wave sound might be able to develop immersive experience. Due to the limited sample size, this result may not properly reflect the consequence, it can be used as reference to prototype development.

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Ordinal by Ordinal	Gamma	-.516	.184	-2.466	.014
N of Valid Cases		21			

Figure 4.3 Gamma Correlation Test Result

According to Figure 4.3, weak negative correlation is suggested between familiarity about ocean and experience of prototype. It indicated that having more understanding and experience with real ocean, the less immersive experience user would have.

During the interview, several participants mentioned that the wave frequency is too fast than natural wave. Noise of pump motor distracted users as well.

4.1.5 Consideration

Following concerns are evaluated for developing the next prototype:

- Wave generator needs to be developed.
- Larger tank needs to be applied in next prototype.
- If temperature module could help to develop better experience needs further evaluation.

4.2. Evaluation User Test for Prototype OpenWater

4.2.1 Test Purpose

As an upgraded prototype, user test is mainly aim to figure out whether developments have positive effect on enhancing user's experience. Two factors is focused in this user test:

- Feasibility of temperature control module.
- Wave generator feasibility comparison with Prototype 2.

4.2.2 Test Participants

Same participants as in user test of Prototype 2 are invited to attend this test. Eventually, 6 people have joint the test. It is hold in Tokyo, June, 2021.

4.2.3 Method

The procedure of test is similar to test of prototype 2. To evaluated the temperature control module(TCM), participants are asked to experience the prototype three times. First test is a test for verifying if board wave generator is more qualified than pump, participants will experience the new prototype under the same condition as in previous test. Second test is based on the data of Ishigakishima, Okinawa, on June, 5th, 2021 with surface temperature of 25°C. Third test uses the data of Hakodate, Hokkaido on same day, which the temperature is 16°C. Questionnaire of Prototype User Test 2(see Table 4.2) will be done from Q1 to Q3 in first test. After second and third tests, whole questionnaire needs to be filled. Regarding the reliability has been already verified in previous test, this step will be skipped during this test.

4.2.4 Result & Analysis

From the result of test shown in Figure 4.4, Figure 4.5, and Figure 4.5, more positive user attitude can be observed.

Table 4.2 Questionnaire of Prototype User Test 2

	Circle the correct numeric response to each question	
	Question	**Survey Scale:** **1=Strongly Disagree** **2=Disagree** **3=Neutral** **4=Agree** **5=Strongly Agree**
1	I can associate the feeling with ocean with I try this prototype.	**1 2 3 4 5**
2	The wave frequency is similar to real ocean wave.	**1 2 3 4 5**
3	There are rarely difference between my hands' feeling of prototype and real ocean when the wave rush to my hand.	**1 2 3 4 5**
4	Temperature changing let me more easily associate the experience to particular ocean area.	**1 2 3 4 5**
5	I never expected the water is so warm/cool even I knew the temperature already.	**1 2 3 4 5**
6	The experience of trying prototype can successfully provide me impression of the particular sea state of the chosen place.	**1 2 3 4 5**

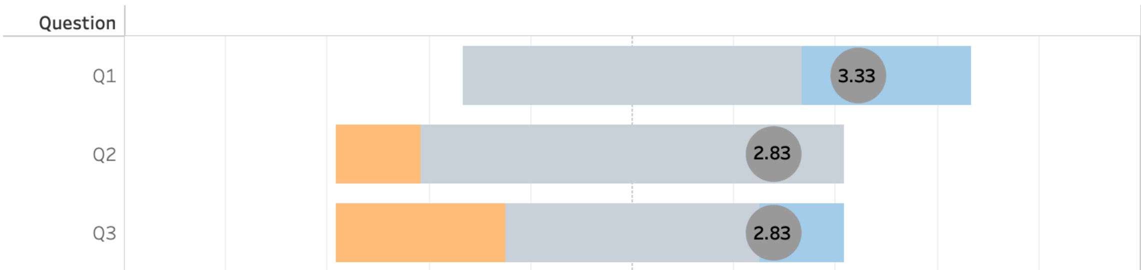

Figure 4.4 Result on First Test(Wave Generator Evaluation)

In wave generator evaluation test (see Figure 4.4), user feedback tends to be positive compare with the result in user test of prototype 2 see Figure 4.2). By

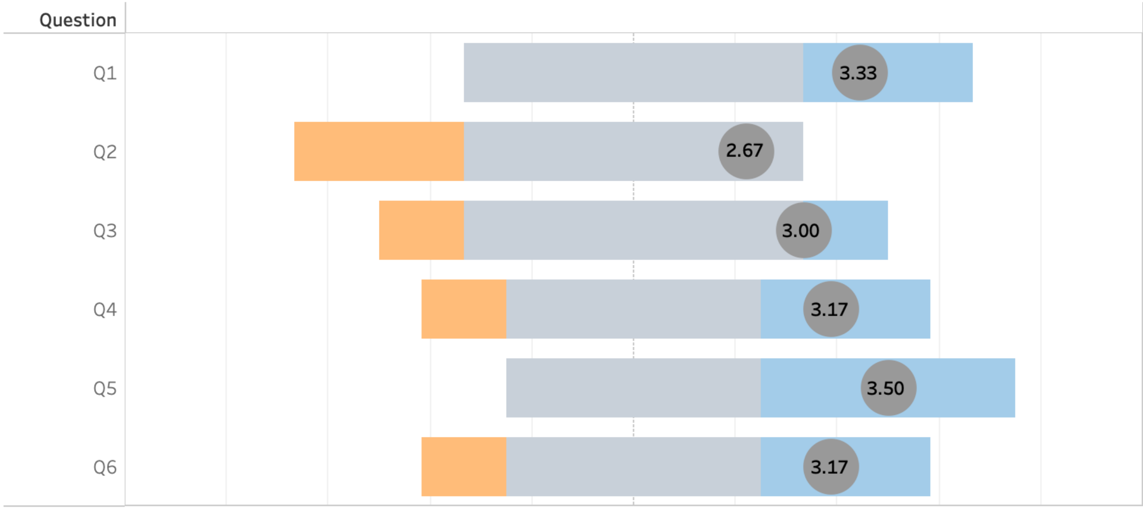

Figure 4.5 Result on Second Test(Ishigakijima, Warm Water)

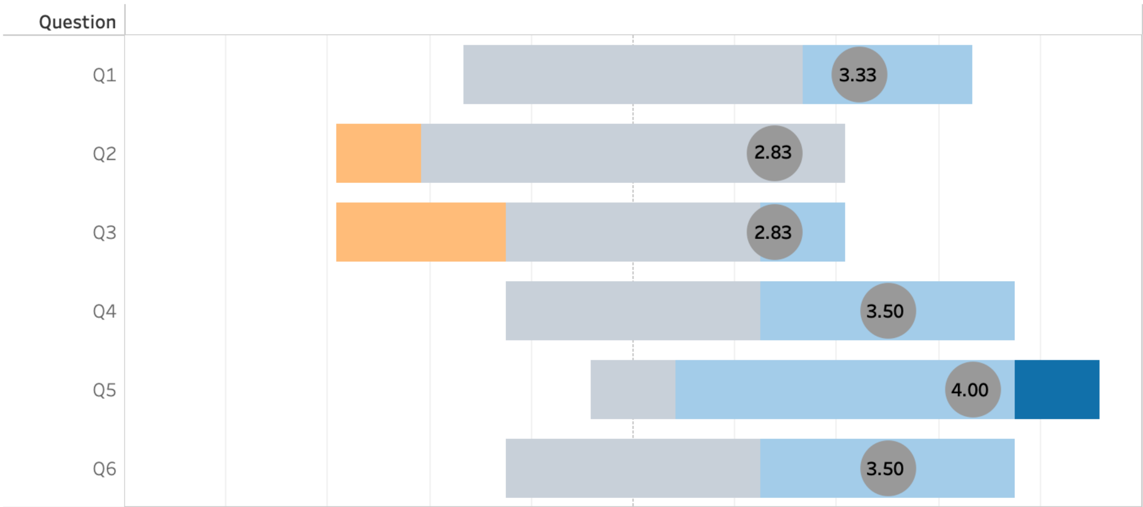

Figure 4.6 Result on Third Test(Hakodate, Cool Water)

calculating the mean value of the same question, it is indicated that the user experience positively increased by 25.23%. Users's attitude of if prototype reached the goal of simulating sea surface shows a slightly positive tendency.

From Figure 4.5 and Figure 4.5, the result suggests that if user can feel the temperature changing of water, he/she might be able to have better immersive haptic experience. Additionally, prototype plays a better role in cool water situation. Since this test was conducted in June, with 23°C indoor temperature, it might be reasonable that the cooler water can provide more direct association with the northern ocean in Hokkaido, because of the larger temperature difference with recent environment and the common impression of Hokkaido (coldest place in Japan). The survey also reflects that people seem to have incorrect expectation of water temperature, accordingly, the prototype may help user to have better understanding on temperature changing of sea surface, which is also a significant factor can have crucial impact on safety of marine activities.

From short interview with participants, they also pointed out several advantages and problems of the prototype OpenWater. One participant, as well as a recreational diver, said "I think it may be helpful if I can experience it before my dive, I can manage my diving suit more properly. Usually, I feel confused when I read the information about dive point temperature. Experience of air temperature is rarely useful to estimate sea temperature." Multiple participants also indicates that the temperature changing time is too long. To cool the temperature from 23°C to 16°C, it usually costs 20-25 minutes. Contrarily, heating also needs even much more time, as well as approximately 40 minutes. Participants also mentioned the wave frequency after adjust tends to be closer to real wave movement.

4.2.5 Consideration

Through analysis of this user test results, it is proved that prototype OpenWater has better performance than Prototype 2.

For wave generator module, basically 3 adjustments are applied to improve prototype. Firstly, value of wave frequency is regulated by involving factor in order to slow down the frequency. The formula utilized in test is:

$$WP_a = \gamma WP \tag{4.1}$$

where

$$\gamma = 0.85 \tag{4.2}$$

Secondly, water pump is replaced by mini flap wave generator module. Thirdly, bigger tank replaced the origin one. It allows user to experience full artificial wave by putting their hands in one side of the tank. Consequently, it is considered as more effective design for improving haptic experience.

Meanwhile, temperature is an essential part of haptic experience. It is clear that user can associate the feeling of their hand with ocean hundreds miles away. It may provide reliable reference for marine activities about sea temperature as well.

However, there are still multiple issues need to be improved. Changing temperature needs to much time with the current module, and there is still room for experience improvement.

4.3. Evaluation User Test for Using Prototype as Marine Activity Reference

4.3.1 Test Purpose

In the section of research goal, hypothesis of haptic experience can assistant people gain better understanding about ocean is assumed. Especially in marine activities, for instance, diving, surfing, or fishing, it is tightly associated with safety issue. This experiment is designed to test the hypothesis.

4.3.2 Test Participants

Five scuba divers with various skill levels participated in this test. Basic information related to this research are listed as below:

- Diver A. Experienced recreational diver. Female in 20s with PADI[1] Advanced Open Water Diver(AOW) licence issued in 2020. Has done over 80 dives, basically in Kando area and Okinawa.
- Diver B. Fresh diver but also skilled freediver.Female in 30s with PADI Advanced Open Water Diver (AOW) licence issued in 2020. Has done about 30 dives, basically in Kando area.

1 https://www.padi.com/

- Diver C. Fresh diver. Female in 30s with PADI AOW licence issued in 2021. Has done about 30 dives, basically in Kando area.
- Diver D. Professional and skilled diver. Male in 40s with PADI Instructor licence issued in 1990s. Has done over 12000 dives mainly in Kando area.
- Diver E. Skilled diver. Male in 20s with CMAS[2] Dive Master(DM) licence issued in 2019. Has done over 500 dives mainly in Okinawa.

4.3.3 Method

Morgan demonstrates that anxiety and panic is one of the most fatal cause in recreational scuba diving [21] in 1995. Accordingly, high level of Surface Air Consumption Rate (SCR) is usually a significant phenomenon which can be observed on panic divers [21].When using 10 Litre air tank, the formula of SCR is:

$$SCR(l/min) = \frac{P_{start} - P_{end}}{T\left(D_{aver} + 1\right)} \times 100 \tag{4.3}$$

Where P_{start} is start pressure of tank (bar), P_{end} is end pressure (bar), T is total dive time (min), D_{aver} is average depth (m).

Being uncertain about factors of dive is usually the main cause of panic. For example, diving with extremely low visibility or unsuitable gears. It is proved that the level of panic and SCR has strong linear correlation [22]. Moreover, over speed breathe tend to cause other fatal disease which is extremely dangerous in diving, such as Decompression Sickness and Hyperventilation Syndrome, is proved in NASA laboratory in 1994 [23]. Hence, SCR is considered as the main variant represents both psychological and physical state of diver.

Therefore, in this research, we apply SCR to evaluate if haptic experience before diving can help divers to be more relax.

Firstly, every diver's average SCR will be calculated through their last 20 logged dives as control data. Secondly,SCR of two dives in one day, with slightly different wave and temperature conditions due to tide change weather. The one recorded in the morning will be a dive in the morning around 9-10am in ebb tide without

2 `https://www.cmas.org/`

using prototype, and another one will be a dive in the afternoon around 2-3pm in flood tide after using prototype for 1-2 minutes. SCR in morning dive is described as SCR2 while the one in the afternoon is described as SCR3 respectively. Every diver's SCR2 and SCR3 will be each recorded at least 5 times, and 2 SCR in one same day will be compared and analysed. Prototype OpenWater will be utilized in this test. All dive data is collected via dive computer Suunto D5, Suunto D4i, Shearwater Teric and Tusa IQ1203P (See Figure 4.7 and Figure 4.8).

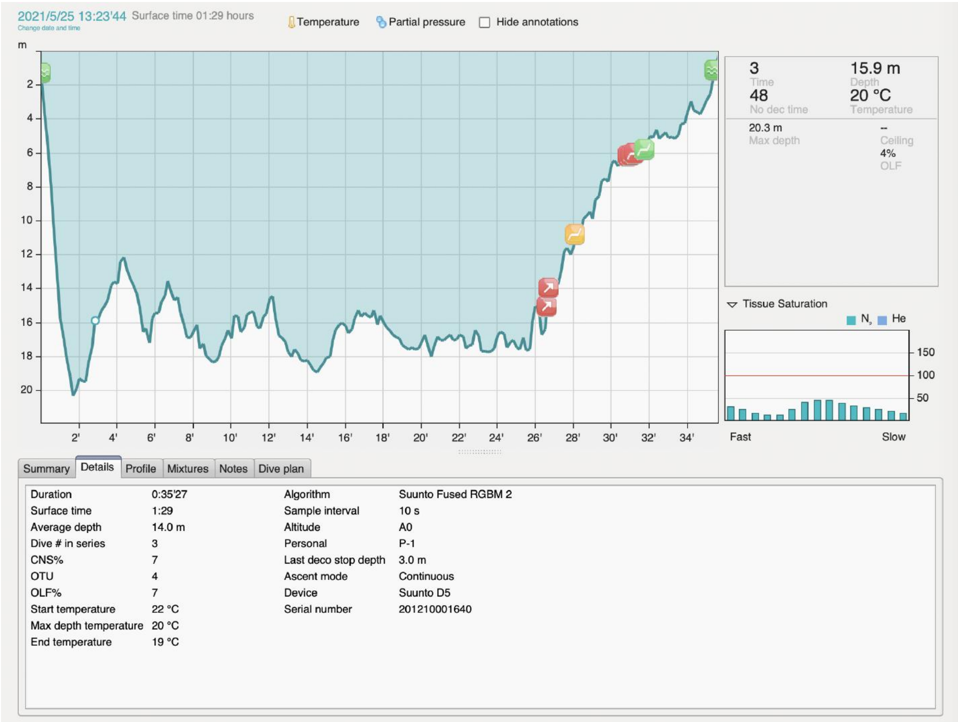

Figure 4.7 Sample of Dive Data Collected by Suunto D5

4.3.4 Test Places

This test is conducted in 2 places:

Hachijo Island

Hachijo Island is a volcanic island located in the Philippine Sea, about 300km from Tokyo. The dynamic sea state and magnificent diversity of sea creatures

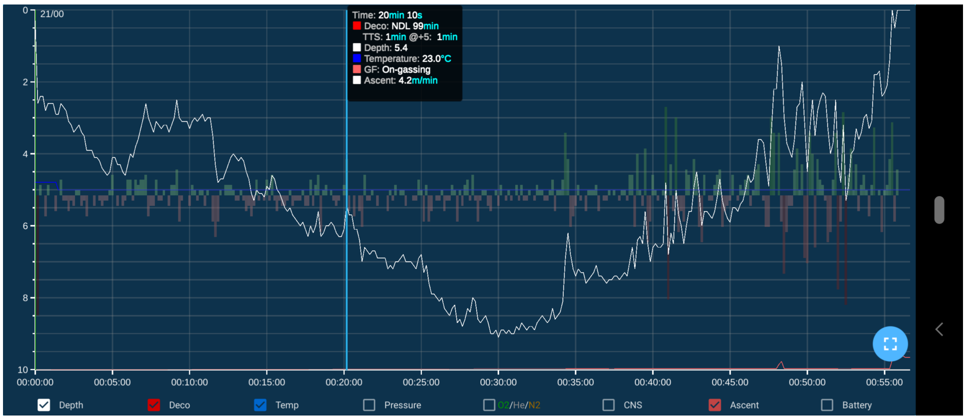

Figure 4.8 Sample of Dive Data Collected by Shearwater Teric

Figure 4.9 Dive Point "Natsumado" in Hachijo Island

makes it famous among divers. It has great beach dive points which suitable for from beginner to professional divers. Nevertheless, as an offshore island, sea state is often unpredictable and unstable (See Figure 4.9).

Mikomoto

Mikomoto is small island located in South Izu, Shizuoka. Because of the passing-by Kuroshio Current. Mikomote is considered as paradise of chasing sharks. Every

Figure 4.10 Dive Boat in Mikomoto, South Izu

summer and autumn, amount of hammerhead sharks can be seen in Mikomoto. However, because of the strong current, only skilled (have done over 50 dives) diver is allowed to dive in this area. It is always a challenge for divers, especially for starters, accidents are not rare in Mikomoto.Every shark chaser diver is suggested not to try Mikomoto after managed advanced drift and boat dive skills. (See Figure 4.10).

4.3.5 Result & Analysis

Table 4.3 SCR Data in Three Test Steps

Diver ID	SCR1	SCR2	SCR3
Diver A	13.42	17.86	16.43
Diver B	13.74	12.84	12.72
Diver C	22.21	16.65	N/A
Diver D	11.28	11.29	11.43
Diver E	14.52	13.77	N/A

Table 4.3 shows the SCR data collected from 5 participants. SCR1, SCR2, SCR3 indicated the result of three steps respectively. Diver A did the second and

third tests in Mikomoto. Diver B and Diver D tested both in Hachijo Island. Diver C and Diver E could not attend the 3rd experiment.

Because lack of experience and swimming against the current, SCR2 and SCR3 of Diver A is apparently higher than her common mean SCR as well as SCR1. SCR decreased 8.0% after employed prototype. However, change is limited in Diver B and Diver D's data. Diver C's SCR declined 1.0% in third test and Diver D's increased 1.2% respectively.

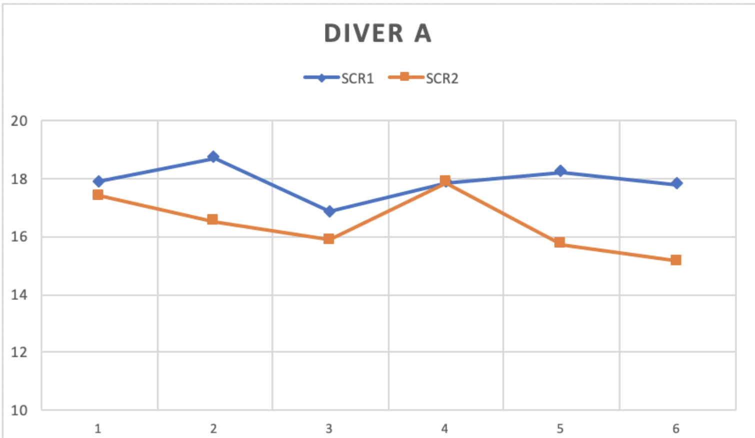

Figure 4.11 Data Comparison of Diver A

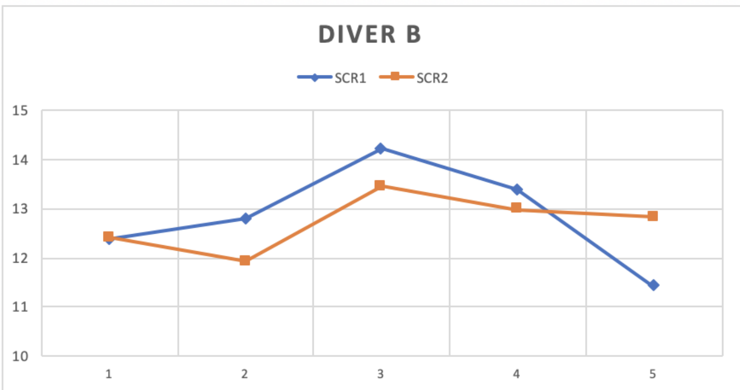

Figure 4.12 Data Comparison of Diver B

Detailed contrast diagrams shows SCR2 and SCR3 comparison of every participants of second and third tests(See Figure 4.11; Figure 4.12 and Figure 4.13).

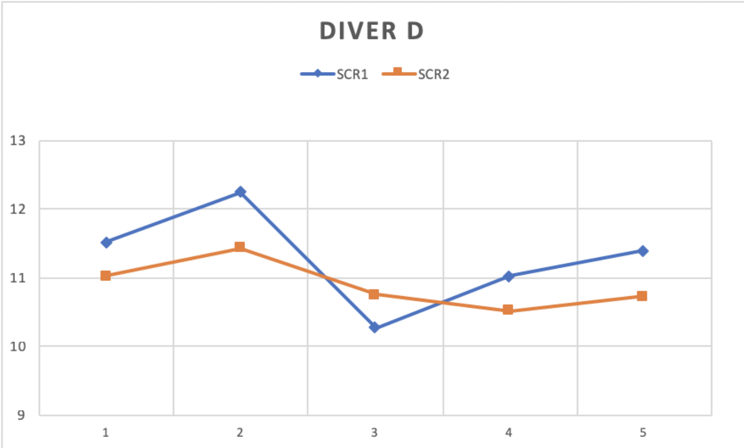

Figure 4.13 Data Comparison of Diver D

From three diagrams, it can be observed that SCR3 is usually lower than SCR2, especially in Diver A's diagram. However, Since the sample is limited to maximum 12 dive per person, it is hardly to perceive the correlation between SCR changing and prototype application.

We also interviewed participant to discus their feelings about using prototype. Diver A mentioned that that was her debut dive in Mikomoto during second test, and she was nervous about the speed of current. In third test, through using the prototype, she was able to build expectation of current, which helps her have more confidence about next Mikomoto dive. Diver B and Diver C both suggested that because they were familiar with the dive point, thus subjectively, they could not have clear feeling that prototype worked for their underwater states. Diver D, as a diver instructor, advised that it may be useful for beginners of scuba diving.

4.3.6 Consideration

Due to the limitation of sample, it is difficult to have reliable conclusion on this user test attempt. However, according to the experience gained from this test, the hypothesis could be improved as: haptic experience may effectively help beginner of marine sports, and when one visits unfamiliar sea area, it may help people draw more specific expectations. Further research on correlation of SCR and haptic experience with more wider scale and more precise analysis need to be scheduled in future.

4.4. Evaluation User Test for users have limited or no physical experience with ocean

4.4.1 Test Purpose

As the United States report mentioned [3], compare with the whole worldwide population, there are numerous people never has the opportunity to visit sea, or physically touch the sea. Therefore, for testing if the design can help people have limited marine experience to gain general physical impression of ocean, in this user test, two participants rarely visit the sea are invented to join.

4.4.2 Test Participants

2 participants who have limited physical marine experience and swim skill participated in the test:

- User A. 20s female Chinese born in inland area, never traveled to offshore area before came to Japan 2 years ago. She never tried any marine sports, and because of drowning experience during her childhood in the pool, she describes herself as slight hydrophobia. She cannot swim at all. She has a plan to visit Okinawa in this summer.

- User B. 20s male Chinese born in inland area. His last ocean experience was when he was 8 years old, with parents in Qingdao, Shandong Prefecture, China. Though he can swim, he tends to show little confidence about his skill, and he has never swim in open water area. After watch the Olympic surfing games, he became interested in surfing, and mentioned if has chance, he would like to try surfing.

4.4.3 Method

During the test, every participants will experience the prototype for 4 times. In the first three times, three different sea conditions are prepared for the test: 1st test, mild wave with 23.0°C sea temperature in Kamakura, Kanagawa; 2nd test, medium wave with 15.0°C sea temperature in Shiretoko, Hokkaido; 3rd test, 3rd test, strong wave with 29°C temperature in Naha, Okinawa.User can decide how long they will put their hand into the prototype by themselves. The length of time, reaction and feedback of user will be recorded. The 4th test would be a continuous sea condition changing procedure, which called "journey of ocean in Japan from North to South". Participants will be asked to put their hand into prototype, then the sea condition will be changed from Shiretoko (as in 2rd test), Kamakura (as in 1st test) and Naha (as in 3rd test). Participants also can decided how long he/she would like to experience every section, when participants require to change the sea condition, it will be changed instantly with their hands still in the tank. Their test time duration, reaction and feedback will be recorded.

Due to the durability of wave generator, longest duration of every test is set as 8 minutes, and it will be informed to every participant before the test starts. There are also 15 minutes break between every test.

Because the operating time of temperature module is too long, in this test, temperature change will use warm water around 42°C and ice cube to make the temperature change more quickly.

4.4.4 Result & Analysis

Table 4.4 Test Duration of Test 1, 2 & 3

Participants	Test1(Kamakura)	Test2(Shiretoko)	Test3(Naha)
User A	73s	34s	30s
User B	82s	50s	62s

In Table 4.4, duration of test of user A and user B are demonstrated.During test 1,2, and 3, it shows that the average duration of test 1,2,3 of user A and B are 45s and 64s respectively. Both participants cost the longest time in test 1, which is the very first experience of prototype. Duration of use A reduces sharply

Table 4.5 Test Duration of every part in Test 4

Participants	Part1(Shiretoko)	Part2(Kamakura)	Part3(Naha)	Total
User A	46s	52s	26s	124s
User B	58s	28s	65s	151s

in test 2 and 3, only less than half of duration of test 1 are counted in test 2 and 3. In user B's result, this obvious reduction has not been observed. He spent both approximately 60s to experience Shiretoko and Naha sea conditions. However, both 2 participants spent least time on Shiretoko test.

Situation in test 4 which results in Table 4.5 shows differences from test 1,2 and 3. Overall, user A spends shorter time than use B, and she experienced Naha with shortest time as well as in previous test. Meanwhile, user B experienced Kamakura least and Naha most.

The feedback of user A and use B will be illustrated as blow.

User A

Test 1:

When test 1 started, she put her hands still in the left side of the tank. After 15 seconds, she started to wave her hand in the water, and finally put her hand near middle of the tank.

She mentioned it is not as fearful as the swim pool or real ocean, because she did not need to put her whole body into the water, and the water is clear that she can notice there is not any unknown creatures in the water which usually makes her nervous when talk about ocean. When asked why she put her hand in the middle of the tank, she explained that she can more clearly feel the wave moves back and forth, which is closer to the sea wave in her impression which comes from videos and photo.

Test 2:

She spoke out "Wow that is really cold, I never imagined the sea water in Hokkaido is so cold even it is in summer." when put her hand again in the tank. She said she can feel the strength differences between test 1 and test 2, but it is actually was not as clear as she can perceive immediately.

She also mentioned because of the temperature, she put out her hand quickly after test started. "The most impressive part is the temperature of Hokkaido sea water, and 30 second for me is enough to experience the change of temperature." she explained.

Test 3:

During the third test, she referred to the next travel plan to Okinawa. She mentioned the giant temperature change in test 2 and test 3, and the wave also become stronger. She was aware of the water splashing out of tank, therefore she stopped the test.

Test 4:

During the Kamakura part of test 4, she said this is her favourite sea condition, because the wave is mild, and the temperature is fit her impression of Japanese ocean in summer, pleasantly cool temperature. However, the water continuously splashed out during Naha part, she had to decide to finish it in shorter time to avoid clothes become wet. She also mentioned she might be afraid if the real wave is as strong as in prototype. Water temperature in Okinawa is also another thing she cares in this experience, she praised the temperature change procedure from Kamakura part to Naha part. "After experiencing the temperature change, I can have a general idea of to what extend Okinawa sea is warmer than Kando area.", she said.

She also mentioned generally, impression of ocean is tightly associated with beach. Therefore, if user can feel the sand texture during the experience, it could deliver better ocean experience rather than a plain tank. Furthermore, a sand texture slope may also help to develop the experience, because it may help users feel wave moving back and forth more clearly as on the beach.

Use B

Test 1:

During the test 1, user B mentioned the noise of motor is disrupting. He also tried to wave his hand against the wave when it is generated. He asked if it is the sea surface of beach or in the middle of ocean, without enough experience of ocean trip, he cannot address clear impression about ocean wave through experiencing prototype.

He mentioned as user A, in his opinion, generally, Kamakura's ocean means "beach area". He felt the generated wave might be quicker than the natural wave, if only put hand into the tank, it is hard to meet the impression of ocean in his mind: great, wide, magnificent.

Test 2:

User B mentioned because he is interested in the ocean creatures in Shiretoko, he spent about 50s in test 2. The temperature of Hokkaido sea also surprised him.

"I know there are no normal beach in Shiretoko, so i feel I can imagine the ocean in Shiretoko more realistic after using prototype, it delivers the picture of in the northern area, cold water, tougher wave, and whales are living underneath." He described.

Test 3:

Compared with user A, user B showed greater interest in stronger wave. He asked if the natural wave is as strong as generated wave, can a beginner surfer ride on it. He can feel the temperature is much higher than Kando area as well. "Warmer temperature obviously address an impression of Okinawa in summer", he said.

Test 4:

During the three sections of test 4, compared with temperature change, use B suggested that the change of wave is still vague, especially the mild wave and medium wave. As well as his recently raised interest in surfing, he suggested wave can be designed in more levels, for example, a specialized model for surfing beginners to quickly have general idea of the different intensities of wave such like safe for beginners, for advanced surfer, and not safe dor surfing.

He also advised that if possible, he want to try the prototype with other part of body, such as feet, because on the beach, people usually put feet into the sea rather than hands. "If the bathtub can be changed into ocean somewhere, that would be amazing." He said during the discussion of design.

4.4.5 Consideration

From the test of users with limited ocean experience, considerations as below are revealed:

- Ocean usually means "ocean near beach area" for these people.Therefore, if the element of beach, for example, sand and tide can be delivered in design, it might be more possible to build impression of ocean for ones who has never been to ocean.

- People may choose to experience the sea area they has interested in. Therefore, it is may necessary to let user to choose the place actively.
- Approximate 60 seconds can be considered as proper time for one user to experience one place.

Chapter 5
Conclusion

This research is focus on simulating the sense of touch to provide immersive experience of ocean regardless the user's location. It targets citizens hold interests in ocean or marine activities. Regarding sea surface temperature and wave movement as haptic description of ocean, a device assembled with water tank, wave generator and temperature controller is assembled. User can choose their interested sea area around Japan to experience local sea state via putting hands into tank.

To sum up, user test results indicate the prototype OpenWater can generator similar wave as surface wave near seashore. Experience shares similarity with real ocean in intermediate level. Users tend to be more impressive to temperature changing rather than artificial wave. Moreover, experiencing sea state before sea activities may reduce one's anxiety level.

However, there are still issues need to be solved. Firstly, though real surface sea wave can be blow to everywhere, with one flat wave generator generate wave in multiple directions is almost impossible. Secondly, operation time of temperature control module is unacceptable long. Thirdly, the number of experiment participants is limited. More participants is required to achieve more precise result.

In addition, being inspired by the user test of prototype of OpenWater, since the wave generator and temperature controller can work separately, the potential of modularization will be considered in future. By attaching modules to change the shape of tank, different form of wave occurs on various land forms can be experienced. How rapidly temperature changed due to greenhouse effect in 100 years can be experienced by one's own hand in minutes. How to improve the design for the purpose of offering haptic experience the activities of marine animals, is also a direction worth consideration. We expect it can contribute to marine knowledge education and guarantee safety of marine activities. The beach module also can be a possible part in future work, in aim to let people have limited chance to go to sea to experience wave on the beach, which more general according to the common sense of ocean of people.

With respect and devotion for our delicate blue planet, we are always expecting that this design could contribute to marine knowledge education, and open an anywhere gate for those have limited opportunity to touch gorgeousness and impermanence of our grand blue sea.

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Appendices