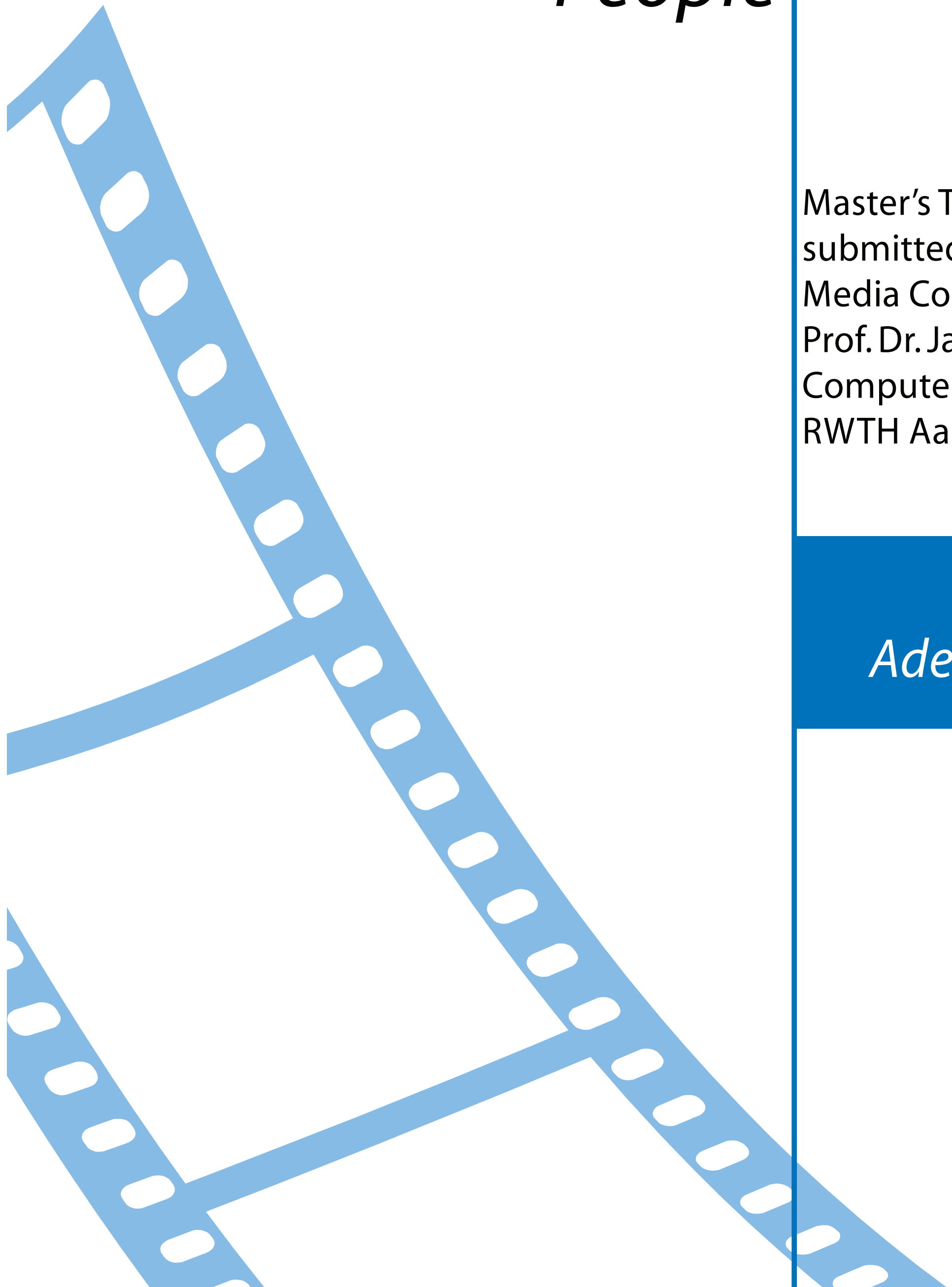
HaptiGuard: Sideway Detection Armband for Hearing-Impaired People



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Abstract

Nowadays, there are many technologies that is used to help those with disabilities to interact like normal people. However, not many technologies are developed for those with hearing disability. One of the problems faced by people with hearing disability is detecting an object outside their field of view. In this thesis we aim to create a technology that helps those with hearing disability to detect an object coming from their sides.

To resolve the problem, we built a prototype called *HaptiGuard*. *HaptiGuard* is a wearable band that detects approaching objects and warn its user through tactile outputs. When building *HaptiGuard*'s prototype, we try several sensors and design. We found that the most suitable design is using ultrasonic sensor with two separate segments: Sensor segment and Feedback segment. We then conduct a user study to test *HaptiGuard*'s precision and effectivity. The user study also test which position is better for *HaptiGuard*'s sensor segment: in the arm or in the wrist.

From the user study, we conclude that *HaptiGuard* is effective at detecting object coming from the side. However, *HaptiGuard* is not too precise to correctly inform user from which direction the object is coming. Our user study also concludes that there's no difference in effectivity or precision whether the sensor segment is equipped in the arm or in the wrist. Overall, we found that *HaptiGuard* will helps deaf people detecting an object coming from their sides.

Acknowledgements

I would like to thank Prof. Dr. Jan Borchers for giving me the chance to do this thesis in i10 chair.

I would like to thank as well my mentor, Dipl.-Ing. Jan Thar. For his continuing support and guidance when I was doing the thesis. I learned a lot from him and I will make sure not to forget them.

To my friends and family, for all their support and help I want to say thank you. Especially to my girlfriend, which become my wing and anchor throughout this process.

And I want to give my special thanks to my mom. I miss you a lot, and I'm really sad that we can't meet again. We had a beautiful goodbye, and I want to present this thesis as my way of saying that I will be alright. I will do my best to always make you proud. I love you mom.

Chapter 1

Introduction

In the recent years, the usage of technology to help those with physical disabilities have been raising. These assistive technologies, along with the development of IoT (Internet of Things), have become cheaper and easier to build as well. However, the development of assistive technology for those with hearing impairment is still too few in comparison with another disability. One of the problem often faced by deaf people is difficulty to detect when an object coming towards them from their side or back. Non-disabled people could detect objects coming from side or back because these object (i.e. car or toddler running) produce sounds, but deaf people could only rely on their eyes.

Car used to have a loud voice that automatically warns pedestrian that a car is coming. However, car nowadays tend to be more silent, or even doesn't have voice at all. While this is good for non-disabled people, this makes harder for disabled people to detect that a car is coming. Therefore, for safety reasons, electrical cars are producing artificial sounds. This helps a lot for blind people, but for deaf people, the problem still stays the same because they can't hear the voice anyway. They solely depends on their eyes to detect when a car is coming.

Human see using binocular vision, which means two eyes combined their view to perceive a single three-dimensional image Fahle [1987]. As can be seen in figure 1.1 , using both

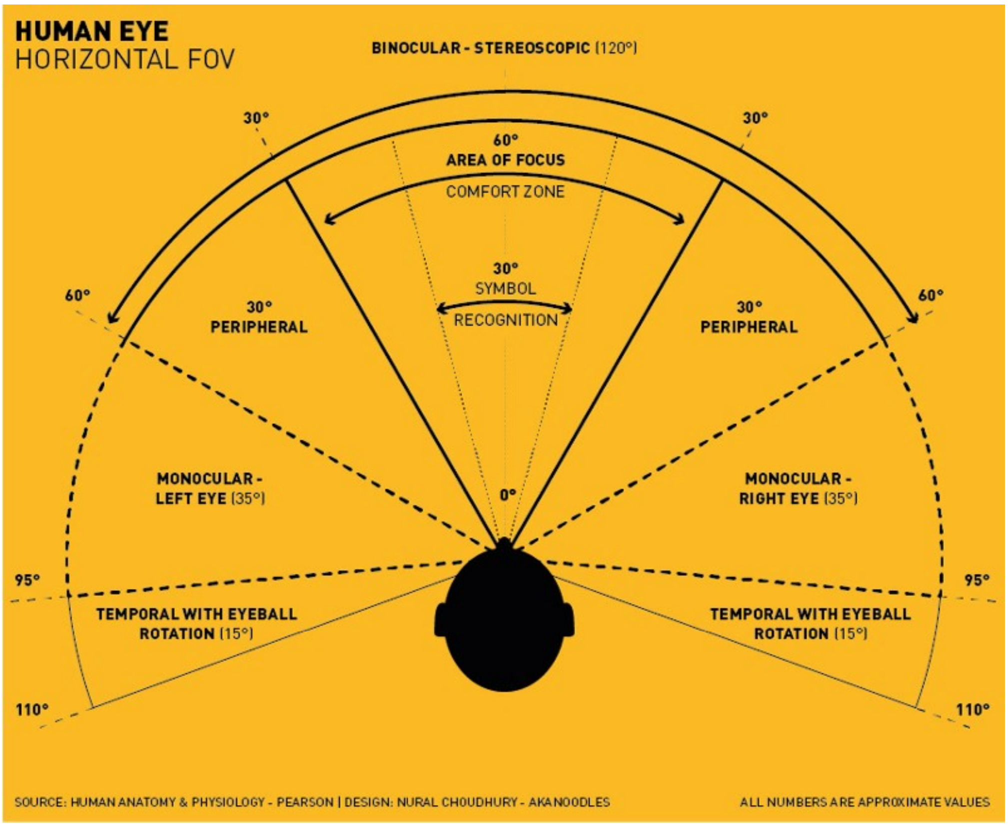


Figure 1.1: Human eye's horizontal FOV. Source: Choudhury [2016]

eyes without moving their head, human's Field of View (FOV) covers around 120°. Each eye covers additional 35° by themselves. Human's side and back are outside the FOV and therefore obscured from eye detection. This obscured area is human's blind spot and its wide are around 170°.

Non-disabled people usually use another stimulus to help detect object in these blind spot, e.g. using sound, smell, or air pressure. The one that human use mostly is sound. But for deaf people, this blind spot is annoying and dangerous since they have to actively use their sight without any help. Thus, is the difficulty faced by deaf people. The needs of assistive device for this problem was expressed to us by our deaf colleague.

When talking about detecting something from the sides, we should put the sensors on an object that is naturally wore on people's side. Arm or shoulder is a good choice since they naturally facing people's side. But putting sensors on people's shoulder might be unnatural because usually people don't put any weight on it. Therefore, we try to explore arm. Putting the sensor in the watch is a good idea. Especially nowadays smartwatch is used by many people. But, since we are talking about sides, that means left and right side. People usually only wears one smartwatch on one arm. And if we put the sensor in the smartwatch, then we only cover one side. Wearing smartwatch on both arm would be strange, so we drop that idea. Instead, we decided to use armband or wristband. They could be used on both hands, and naturally facing the sides. The next question is which one is better? An armband or wristband?

The focus of this research is to create a system to help reduce human's blind spots, especially for aiding deaf people. As a result, we create a system called *HaptiGuard*. *HaptiGuard* is a wristband / armband that could aid deaf people detect an object coming from the side.

Later we evaluate how effective and precise this tool is through a user study. In this user study, we also want to answer the question: which position is better for this tool? On the wrist or on the arm?

Chapter 2

Related work

In the topic of helping disabled people walking outdoor, sadly only few devices were developed to help deaf people. More works are more focused to help those with visual disabilities instead.

Since most of visually impaired user use cane to navigate themselves when going outdoor, Paul et al. [2007] improve a cane and developed SmartCane. A usual cane could only detect knee-high object within 75 centimeters range. But, by enhancing a usual cane with ultrasonic vibration sensor,

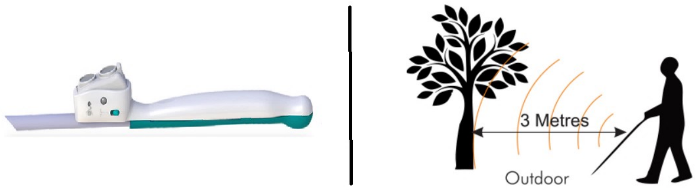


Figure 2.1: Smart Cane by Paul et al. [2007]

SmartCane greatly enhance the detection point of a cane. It enables blind people to detect object higher than knee-high object within 3 meters range.

Ramadhan [2018] developed Wearable Smart System (WSS) to help visually impaired people walk in the outdoor. WSS device use microcontroller, sensors, phone, and GPS. The system is worn on user's wrist and detect any object in front of the user. The output is then sent via voice and vibration to the user. WSS also detects user's distress call and then automatically send SMS containing user's current location

Figure 2.2: Wearable Smart System (WSS) by Ramadhan [2018]

to user's family / caregivers.

Since Ramadhan [2018] and Paul et al. [2007] were developing devices for visually impaired people, their detection point is more focused on user's front side. Deaf people have little to no problem detecting object in their front and therefore Ramadhan [2018] and Paul et al. [2007]'s device have little use to them. However, some of its concept could be used for developing tools that helps deaf people since the concept is roughly the same.

One approach to help deaf people is by visualize sound into visual cues. Visaural by Gorman [2014] is glasses that detects sound, and then provides light that warns its user regarding the source and intensity of the sound. Visaural use an array of microphones as input and two LEDs on left and right lenses as output. The microphones detect whether the sound comes from left or right of the head, then turn on the corresponding LED.

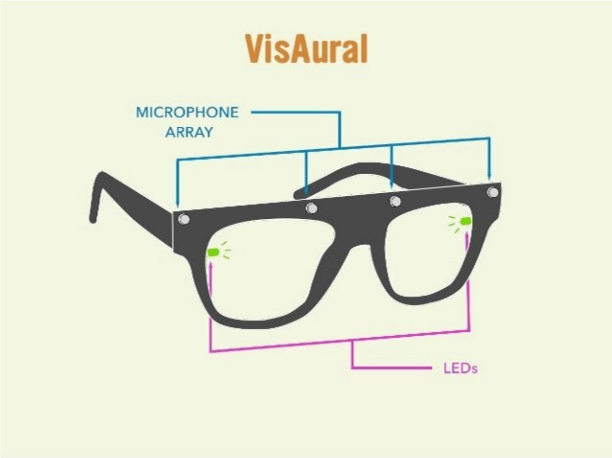


Figure 2.3: Visaural by Gorman [2014]

Almost similar to it, is the system developed by Profita [2014] that transform sound into tactile feedback. Profita [2014] create a Smart Garment that consist of a garment with a network of microphones and co-located coin vibrators. Microphone that capture sound will then relay the information to related coin vibration motors that vibrates to inform its user.

Answering to the problems of deaf people's difficulty detecting car that comes from their behind is Lee et al. [2016]. LaneMate is a car sensing system that consist of two parts: car detecting part and feedback part. Car detecting part is used to detect incoming cars and composed of ultrasonic sensor, sound analog sensor, Bluetooth module, and microprocessor. It is worn on user's waist with the sensors facing user's rear side. Feedback part is in charge of notifying user when a car is detected by car detecting part. It is worn on wrist and consist of vibration motors, Bluetooth module, and microprocessor. The review for LaneMate was quite positive, with criticism comes mostly because the device is too heavy to wear and the feedback given was too late.

Chapter 3

HaptiGuard - Prototype

In order to create a tool that helps people detect their side, we design a prototype that appropriately fulfill that purpose. We tested several types of sensors, tried some design to mount the systems to the armband, and tested which design is the most dynamic for different type of peoples.

Our aim when building the prototype is to create something that is not too heavy, and could be used at ease by different type of peoples.

3.1 Prototype Creation

We separate the prototype creation into three steps: testing the sensors, designing the house for sensor, and mounting the system to armband. After that we tried out the prototype and then make another improvement based on our personal experience when wearing the prototype.

3.1.1 Choosing The Sensor

In order for the prototype to be useable, we set several criteria to be fulfilled by the sensors. First, the sensors should

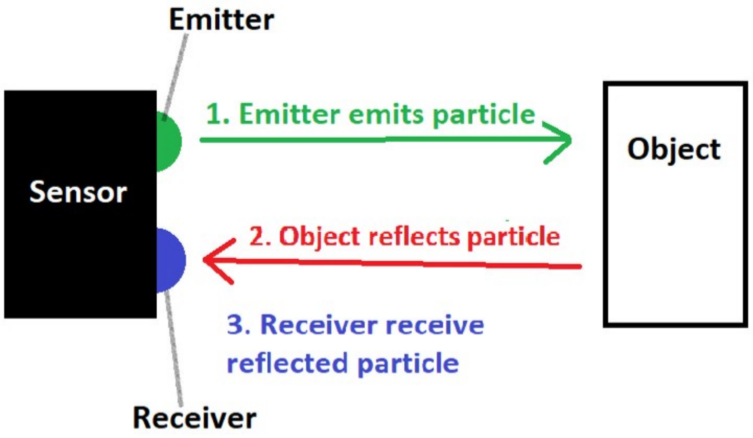


Figure 3.1: ToF illustration

be able to detect more than 1 meter. 1 meters is the minimum distance to warn people that something is approaching them. Less than that will be too late for people to react accordingly. Second, the sensors should be able to be used outdoor. Every sensor has limitations, but we will choose sensor which limitations is not hindering the sensor to be used outdoor. Third, the price of the sensor should not be too high. We are trying to cover a large blind area and we may need more than one sensor in our prototype. Therefore, the price of the sensor should not be too high. And last criteria, the size of the sensor should not be too big. Since the sensors should be easily to be mounted on the armband.

Most of the sensors used to measure distance is using Time of Flight (ToF) principle. ToF principle works as follows: the sensor emits a particle, the particle then hits an object, and then the particle reflected back to the sensor. The distance is measured based on the time between emission and reception of the particle. An example of sensors that is using ToF principle are ultrasonic sensor that used ultrasonic waves as its particle, and LIDAR (Light Detection and Ranging) sensor that used light as its particle. The illustration of ToF principle can be viewed in figure 3.1.

Our original plan is to combine between ultrasonic sensor

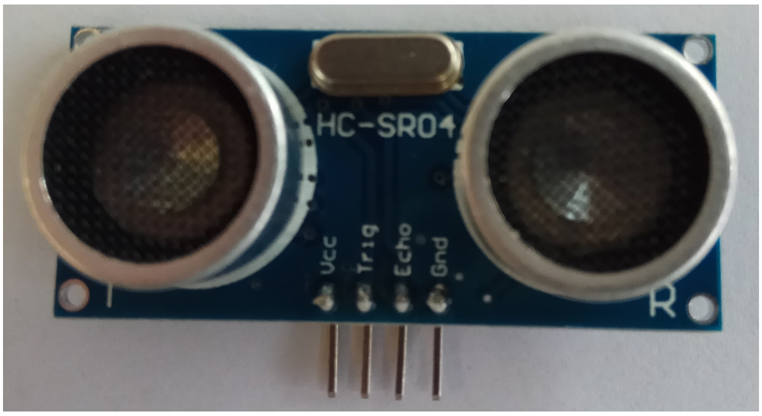


Figure 3.2: Ultrasonic sensor HC-SR04

and LIDAR sensor. Our hypothesis is the combination between these two types will give us better overview of the surrounding. For that reason, we tried several kinds of ultrasonic and LIDAR sensor.

The first sensor we tried is Ultrasonic sensor HC-SR04 (figure 3.2). We connect the sensor to an Arduino UNO and a bread board, then test its distance and sensitivity. HC-SR04 could detects until 4 meters and could easily be mounted on the armband. Its weight and shape is also ideal to be wore on an arm. So, we will put this sensor as one to be used in our prototype.

The second sensor we tried is laser sensor VL53L0X (figure 3.3). Again, we test the sensor by connecting it to Arduino UNO and breadboard. When we checked its detection range, VL53L0X can only detect until 20 cm because it only carries a small light source. Even though it's really small and adequate to be attached in armband, we decided not to use this sensor in our prototype. If newer and stronger version of VL53L0X is available, it might be feasible to include this sensor to our future prototype.

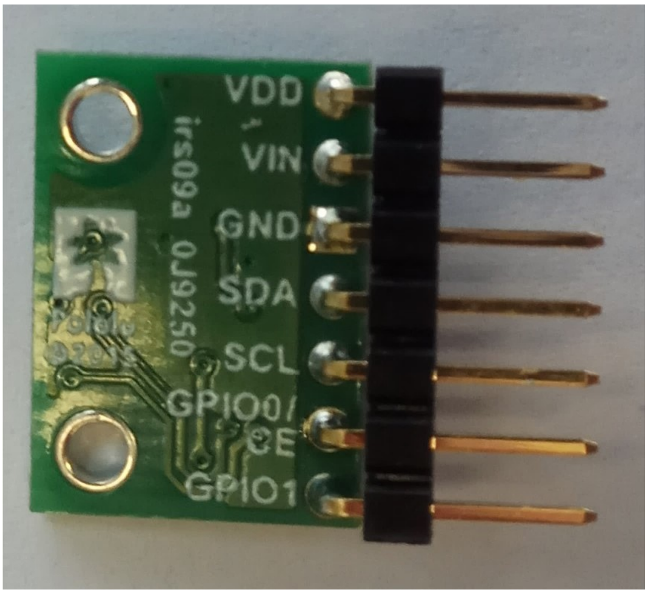


Figure 3.3: Laser sensor VL53L0X

The third sensor we tried is another ultrasonic sensor LV-EZ1 (figure 3.4). We connect it as well to Arduino and breadboard to test its range. LV-EZ1 can detect until 4 meters and its conic range is satisfiable as well. Its shape is small so mounting it to armband should not be a problem. However, LV-EZ1's price is a lot higher than HC-SR04. We didn't test between LV-EZ1 and HC-SR04 further because in our context both sensors work well and only have little difference. But, as we may need to use more than one sensor in our prototype, we decided not to use LV-EZ1 because HC-SR04 is a lot cheaper.

The fourth sensor we tried is TFmini-LIDAR (figure 3.5), an infrared LIDAR sensor. We found difficulties when trying to connect this sensor to Arduino UNO as well as breadboard. TFmini's original jumper wire is too small to be connected to Arduino UNO or breadboard, so we have to cut its original jumper wire and connect it with another bigger jumper wire to Arduino UNO. But even after TFmini is connected to Arduino UNO, the sensor doesn't seem to work. After several researches, we found that TFmini could only work with specific type of Arduino. In this case, Arduino Mega or Seeeduino Lite. We then connect TFmini with Ar-

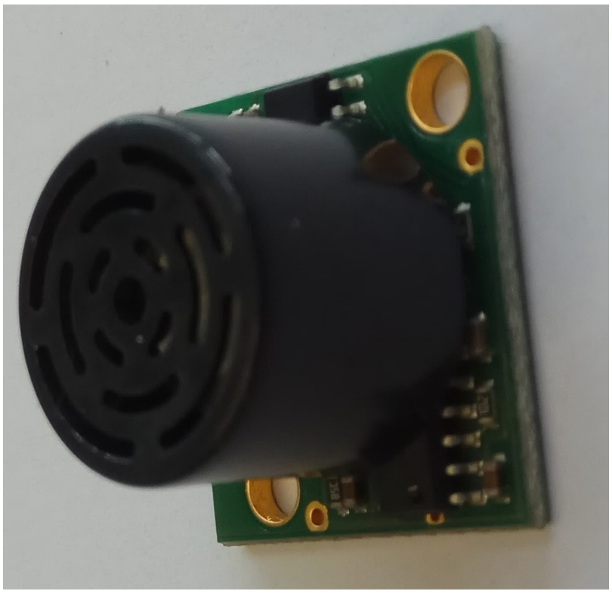


Figure 3.4: Ultrasonic sensor LV-EZ1

duino Mega and the sensor works successfully. Using our code, we find that TFmini range is good and can reach until more than 4 meters. Its range is definitely better than VL53L0X. However, we found that this sensor doesn't work well when detecting glass object and have very small field of view. If we want to cover 45° detection range, several sensors will be needed. We decided not to use this sensor in our prototype for two reasons. First reason, because this sensor doesn't detect glass object well. This inability could be fatal as a lot of stuff nowadays are made from glass. Second reason, because its price is quite high and if we want to cover wider angle we will need to use more than one sensor.

In conclusion, we decided to use only HC-SR04 in our prototype as this sensor is the most suitable to be used outdoor. Its range is adequate, the shape is small and easy to be mounted, the price is low, and it could be used outdoor without affecting its performance. It's a shame that we didn't able to find LIDAR sensor that could be used in combination. But this should not affect the coverage nor performance of our prototype because several ultrasonic sensors will be able to cover those blind spots.

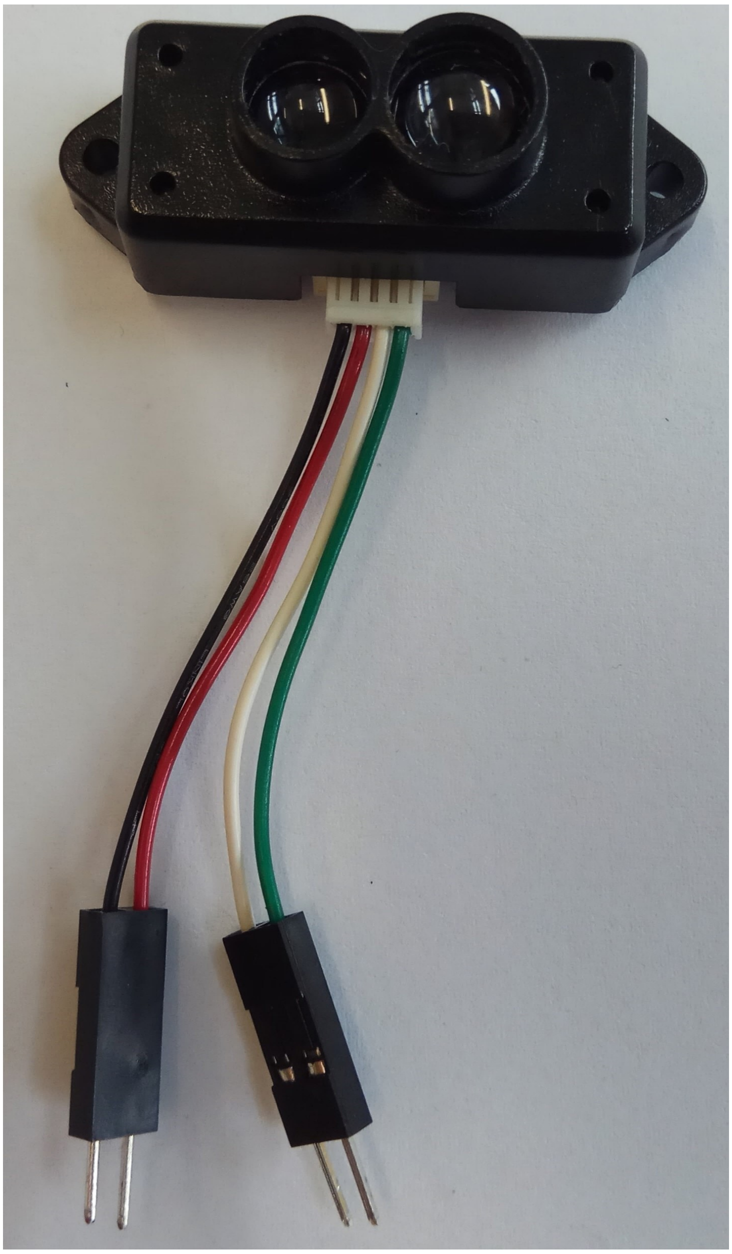


Figure 3.5: TFmini LIDAR

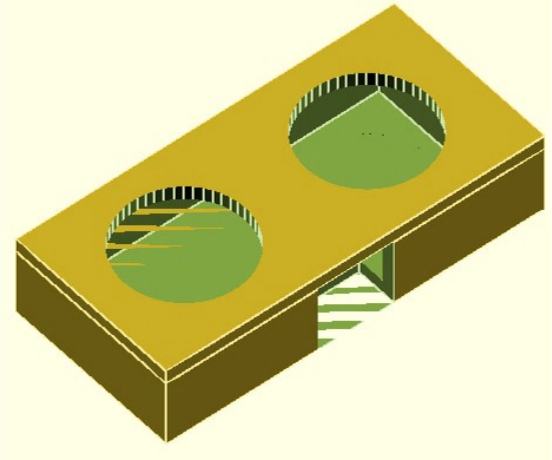


Figure 3.6: HC-SR04 case

3.1.2 Designing The House For Sensor

When designing the house for sensor, we aim to reduce human's blind spot around 80° – 120° on the left and right. That means around 40° – 60° for each side. HC-SR04 approximately have 15° detection angles. By combining three of them in one side, we should be able to reduce the blind spot by 45°.

Therefore, when we design the house, we have several criteria to be fulfilled. First, the house should contain three sensors and cover the area around 40° – 60°. Second, the house should be flexible to be worn by anyone without affecting its coverage. Taking into consideration as well is different arm size between each person. Because we also planning to test different location for the sensor, we should also design the house so it could be worn on arm and on wrist.

Before combining the three sensors, we design a simple house for HC-SR04. The house is just a simple case from PLA (polylactic acid) and we 3D-printed it using 3D printer Ultimaker. We have to print and re-design the case several times before eventually able to fit the sensor inside the case. The picture of the case can be seen in figure 3.6.

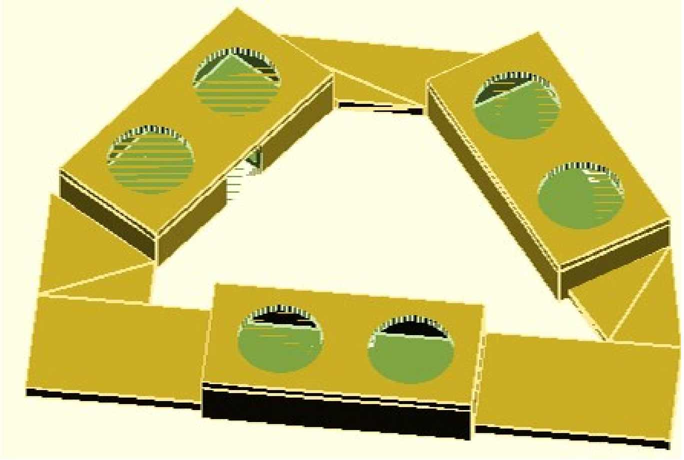


Figure 3.7: Triangle design

The first design we tried is what we called the triangle design. As can be seen in figure 3.7, the three sensors form a triangle with a sensor on each triangle's side. The advantage from triangle design is the overall size is small so it fits whether used on the hand or the arm. But, the problem with triangle design is the range it covered. Triangle design only covers around 30° since the intersection area between each sensor is too small. The bottom sensor basically detects the same area with either left or right sensor. The bottom sensor expands the detection area vertically instead of horizontally.

The second design that we tried is H-Case design. H-case design like its name, is formed like a capital 'H' letter (see figure 3.8). With H-case design, the detection area covers 60°. We print this design using PLA material. However, when we tried to mount it to the armband, it couldn't bend according to user's arm. The middle sensor covers arm's area that faces the side while the right and left sensor are hanging. If we try to bend the H-Cases so its fully attached to the arm, the middle sensor will break. Therefore, we require another design.

Our third design is I-Case design. To solve H-Case problem, this time we avoid putting any sensors horizontally in order to make room on the arm for three sensors. Instead,

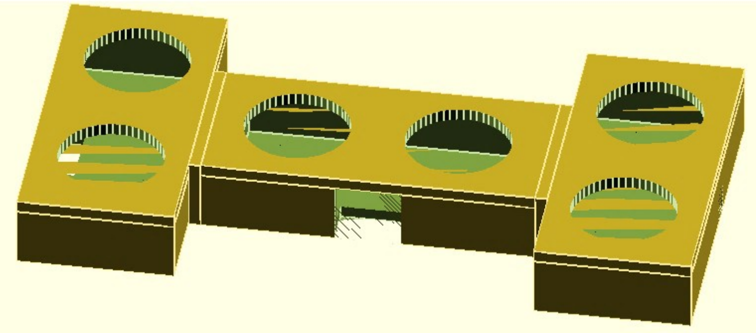


Figure 3.8: H-case design

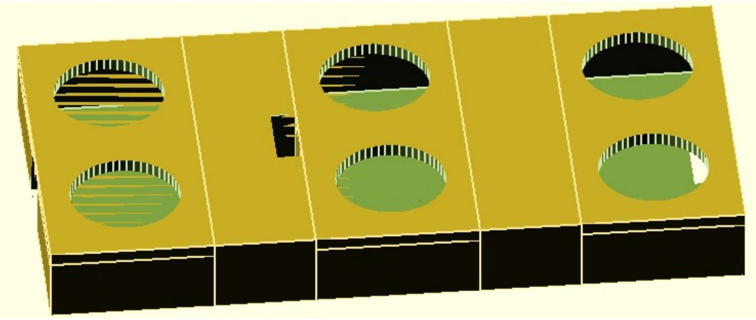


Figure 3.9: I-Case design

we line up the three sensors vertically and make a connector between them (see Figure 3.9). I-Case's design's detection range is 45°. We 3D-printed I-Case design with PLA material. I-Case design fits on the arm and its detection range is satisfiable as well. However, when we put I-Case on the wrist, it's not flexible enough and only some part could be attached to the wrist while the rest are hanging.

The main problem with I-Case and H-Case is they are not flexible enough. Before we come up with another design,

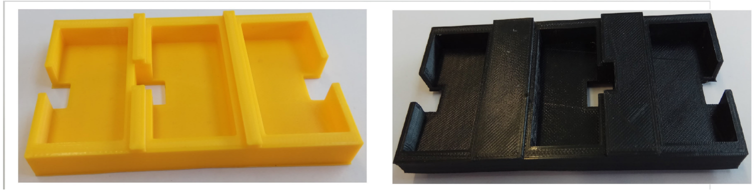


Figure 3.10: Case printed with two different material. Left, using PLA material. Right, using TPC flex material

we tried instead to tackle this flexibility problem by using different material. PLA is not flexible enough for our case, so we choose another material; TPC flex 45. TPC (Thermoplastic Co-Polyester) has high carbon content that makes it far more flexible and durable in comparison with PLA. TPC flex is basically a flexible rubber that could bend and stand heat better than regular rubber. Using another 3D-printer, Prusa i3 mk2, we print I-Case and H-Case with TPC flex material. The comparison between cases printed with PLA and TPC flex could be seen in figure 3.10.

The problem with TPC flex H-Case is still the same with PLA H-Case: The middle sensor is not flexible enough to be worn on the arm. Even though the TPC flex H-Case is flexible, the sensor (HC-SR04) is not flexible. Therefore, TPC flex H-Case still fail to fulfill our requirement. The problem with TPC flex I-Case is, it's still not flexible enough. When the TPC flex I-Case is used on the wrist, it could bend a little, but it immediately returns to its original shape. Even using TPC flex, our most flexible material in the FabLab, we couldn't handle this flexibility issue. So, we move to create a new design.

Our fourth design is I-Wing design (see 3.11), an improvement of TPC flex I-Case. TPC flex I-Case flexibility is

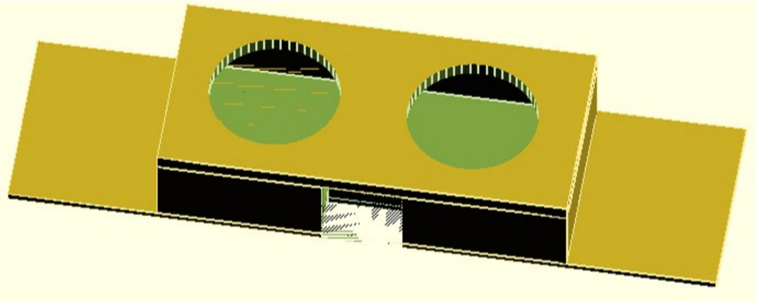


Figure 3.11: I-Wing design

not that high because the separator between sensors is too thick, so it immediately come back to its original shape after bending a little. I-Wing design improvement is the reduction of the separator's thickness. We also add some kind of "wing" for each sensor so it could be attached to armband easily. We print I-Wing design using TPC flex material. When used on the arm, this design fits well and its detection range is satisfiable as well. Another good thing about this design is its detection area is absolute because the distance between sensors are static. However, that's also I-Wing design weakness. Because if it fits well to one person, it won't fit for another person that have different arm measure. When it is to be worn on the wrist, we could measure a person's wrist and then print the correct measure. But another person won't be able to use it because they have different measurement.

We found that I-Wing design would be the best if it is aimed for personal use. However, because we need our prototype to be used by several people, we need another design that is more flexible than I-Wing design. Therefore, our fifth design is a lot simpler. We call it Wing design (see figure 3.12) and it's basically a downgrade version of I-Wing design. We remove the separator between each sensor so the sensors could be adjusted to each person's arm size as well as wrist size.

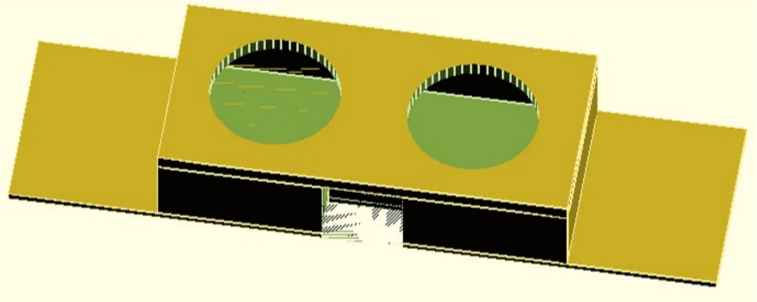


Figure 3.12: Wing design

Wing design is modular, so if we want to add, remove, or even replace the sensor, it could easily be done. For different kind of setup where more sensor or feedback is required, as well as another setup where we broaden or shrink the detection range, wing design could easily adapt to those. And the most important thing, wing design could be adjusted to have fixed detection range regardless the arm size.

With the wing design, we finally found a design that fulfill all of our requirement. It's detection range is around 45°, and its flexible enough to be used by anyone despite their arm or wrist size. When wing design is equipped (see figure 3.13), each sensor's position could be adjusted so they will form the correct detection range and facing the correct direction as well. We can now proceed to mount the entire system to the armband.

3.1.3 Mounting The System

Our system as for now consist of three big parts: the vibration motor as feedback, an Arduino, and ultrasonic sensors (figure 3.14). The vibration motor that we use is the simple one with pins and bracket like the on in figure 3.15.

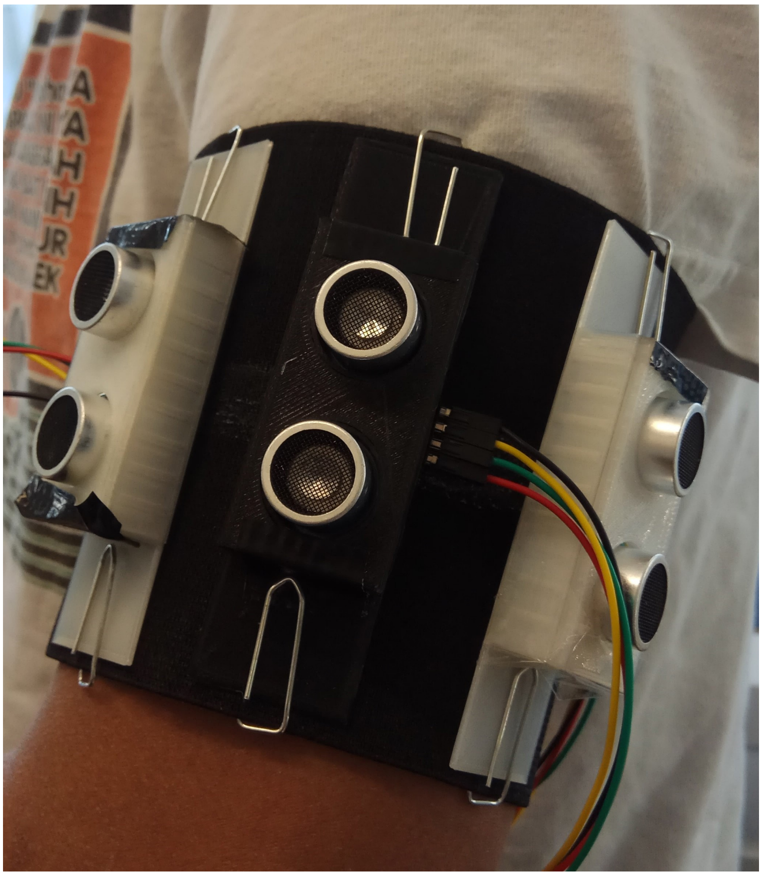


Figure 3.13: Wing design when equipped

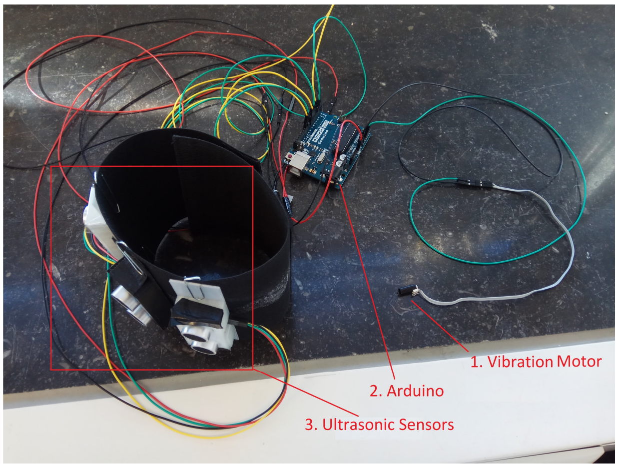


Figure 3.14: Raw Haptiguard prototype

We also have to add a battery as well to the system as a power source. As for now, the system should be ready to be mounted and tested.

When we tried to mount the whole system to the armband, we realized that the armband is too small to contain all four parts. We could fill the whole armband with the system, but that would mean some part will be worn on the inner side of the arm. Wearing something on the inner side of the upper arm is weird and distracting, so we tried to avoid it. Therefore, we decided to separate the system into two different parts: feedback part and sensor part. Sensor part consists of three ultrasonic sensors, and feedback part consists of Arduino, battery, and a vibration motor. For clearer description of the two parts, see figure 3.16 left. This way, all system's part is equipped on the outer side of the arm and we prevent the distraction. Our prototype is now ready to be tested.

After we equip the prototype and tested it ourselves, we realized that the output of the system is lacking. First problem is the vibration motor that we used is not suitable. Its vibration is too weak, the motor often jammed, and it keeps coming loose from the armband. Second problem is unbalanced amount between input and output. There are three inputs (ultrasonic sensors), but there's only one output (vi-

Figure 3.15: Vibration motor with pins and bracket

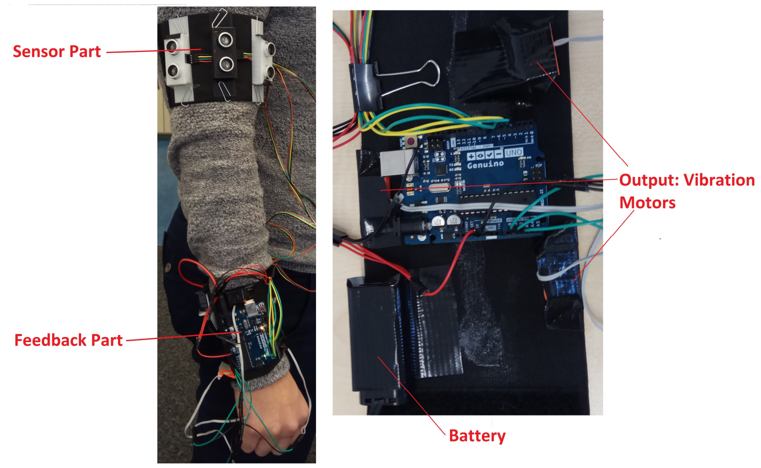


Figure 3.16: Left, two parts of HaptiGuard system. Right, inset of Feedback Part

Figure 3.17: Vibration motor with metal protector

bration motor). To fix both problem, we improve the prototype by adding two more vibration motors adjacent to each ultrasonic sensor and put them in a simple case. As can be seen in figure 3.16 right, we put the vibration motors in triangle form. Each of them represent the ultrasonic sensor location as well as the direction of incoming object: front, middle, and back. We don't want to put them in one straight line because it will be hard to detect the middle output.

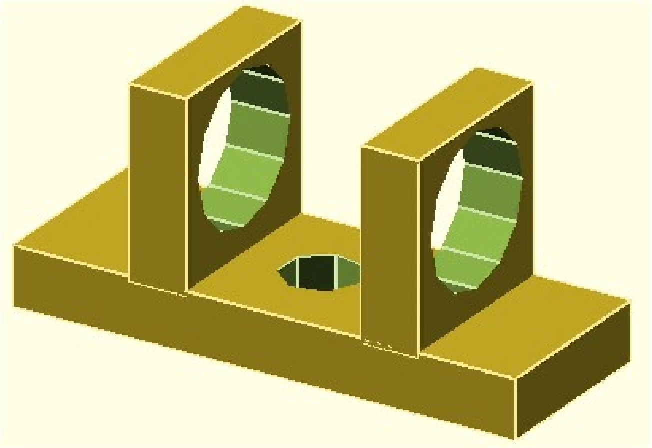


Figure 3.18: Case for vibration motor with metal protector. The holes in the middle is used to sew the case to the armband

We equip again the prototype and test it. But turns out, the vibration motor still keeps jamming. We finally decided to change the vibration motor and built appropriate case for it. This time we choose vibration motor that have metal protector to prevent jamming and have stronger vibration (figure 3.17). For the case, we design and 3D-printed a case to keep it attached to the armband (figure 3.18). We also do another improvement for our prototype. Taping all parts with duct tape is simple, but turns out it's not enough because after some time the tape become loose. Therefore, this time we sew Arduino, battery, and vibration motors to the armband.

With our last improvement, we are done with the prototype. We test the prototype and the system works as we expect them to be. As can be seen in figure 3.19, the final version contains metal vibration motor in three location, along with three ultrasonic sensors with its adjacent position.

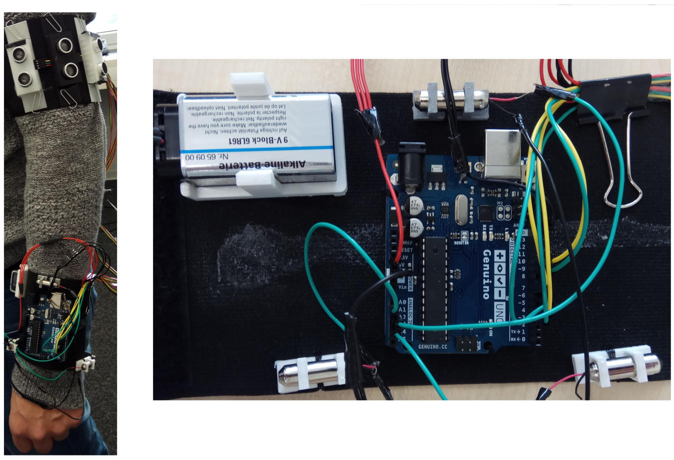


Figure 3.19: Final version of the prototype. Left, when the prototype is used. Right, inset of feedback part.

3.2 Implementing The Code

The code for our prototype is very simple. We only implement three codes in total: code to test the sensor, HaptiGuard code version 1, and HaptiGuard code version 2.

3.2.1 Code to test the sensor

To test the sensor, we connect it with a bread board and an LED. If the sensor return any value higher than zero, then the LED will be turned on. Of course the detail code would be different according to which sensor is being tested. But in general, the flowchart of this code is shown in figure 3.20.

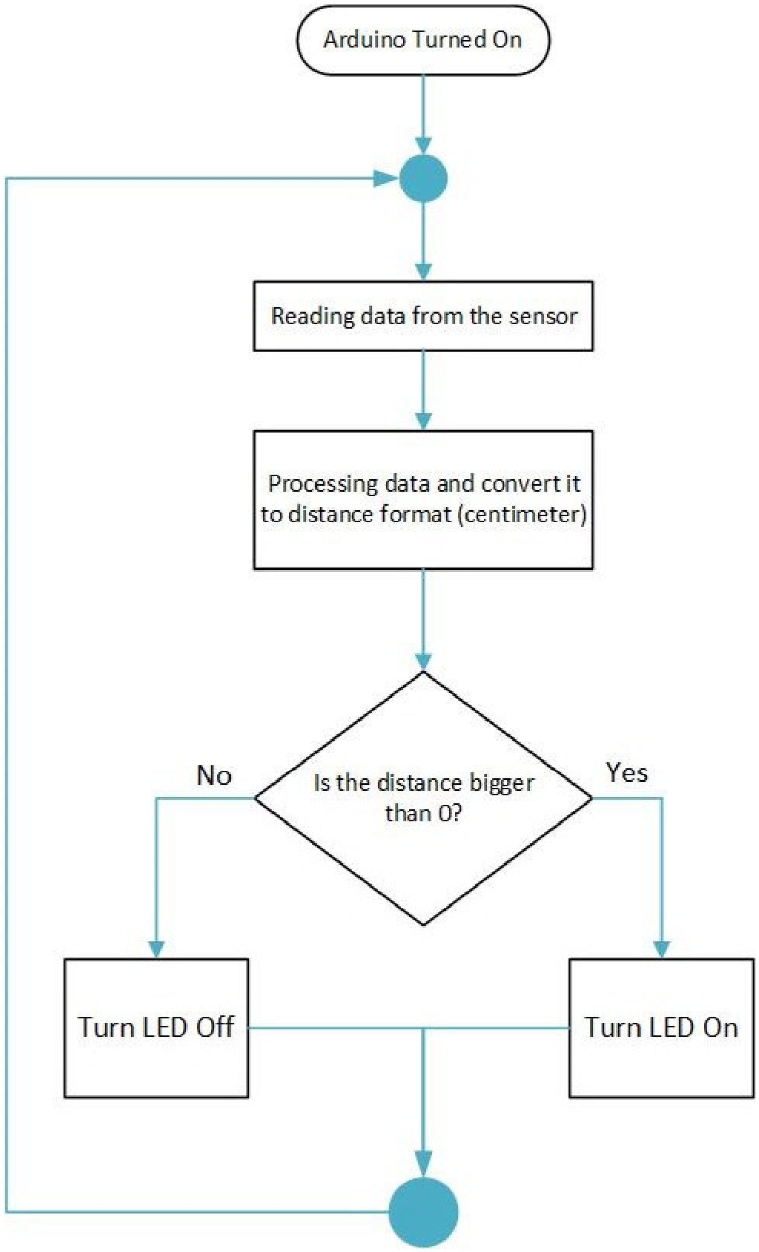


Figure 3.20: Flowchart of testing the sensor code

3.2.2 HaptiGuard version 1's code

In the first version of *HaptiGuard*, we only have one vibration motor. Therefore, our flowchart is simple as shown in figure 3.21. We set the critical distance to 150 centimeters, and then loop through all sensors attached. If any of the sensor read distance less than critical distance, then turn on the vibration motor.

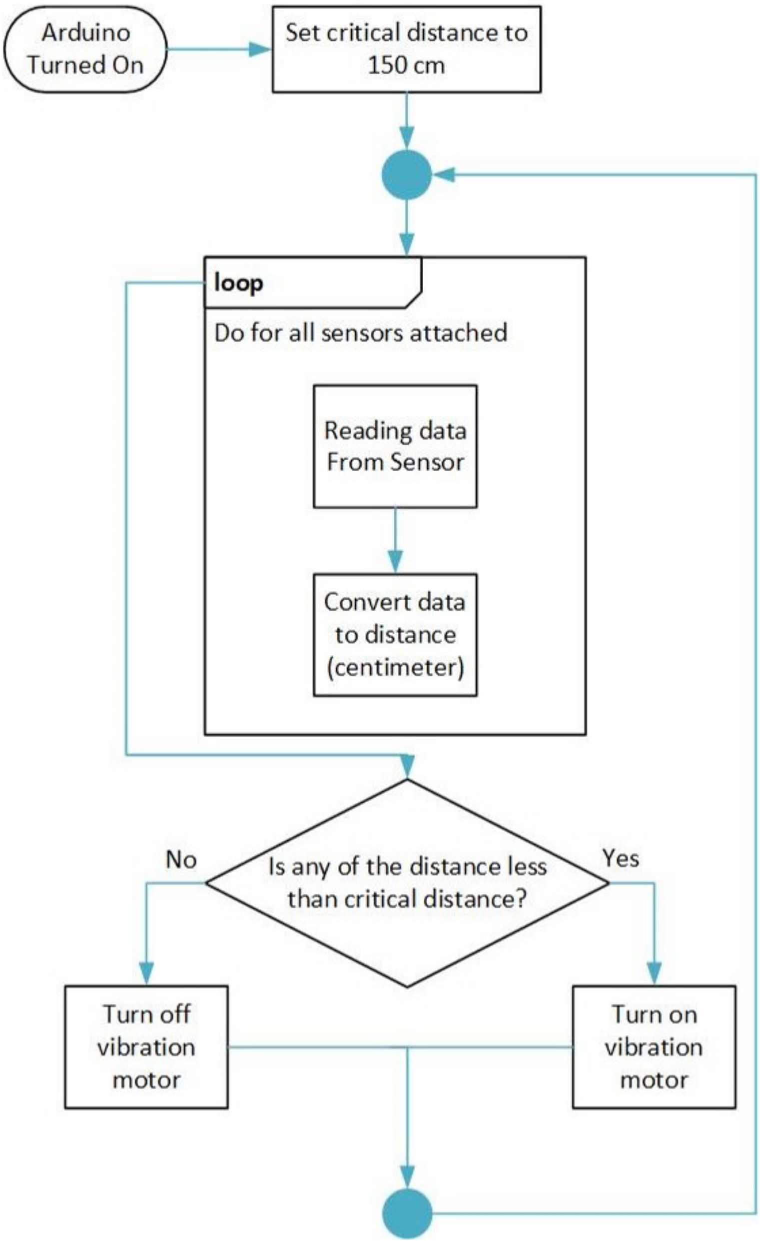


Figure 3.21: Flowchart of *HaptiGuard* version 1

3.2.3 HaptiGuard version 2's code

In our second version, we decided to add two additional vibration motors. We also reduce the critical distance to 100 centimeters, since our pilot test point out that 150 centimeters is still too far to notify user that something is coming towards them. The flowchart is quite similar to version 1. The difference is each sensor has corresponding vibration motor that will be turned on when the sensor detect something less than critical distance. The flowchart can be seen in figure 3.22.

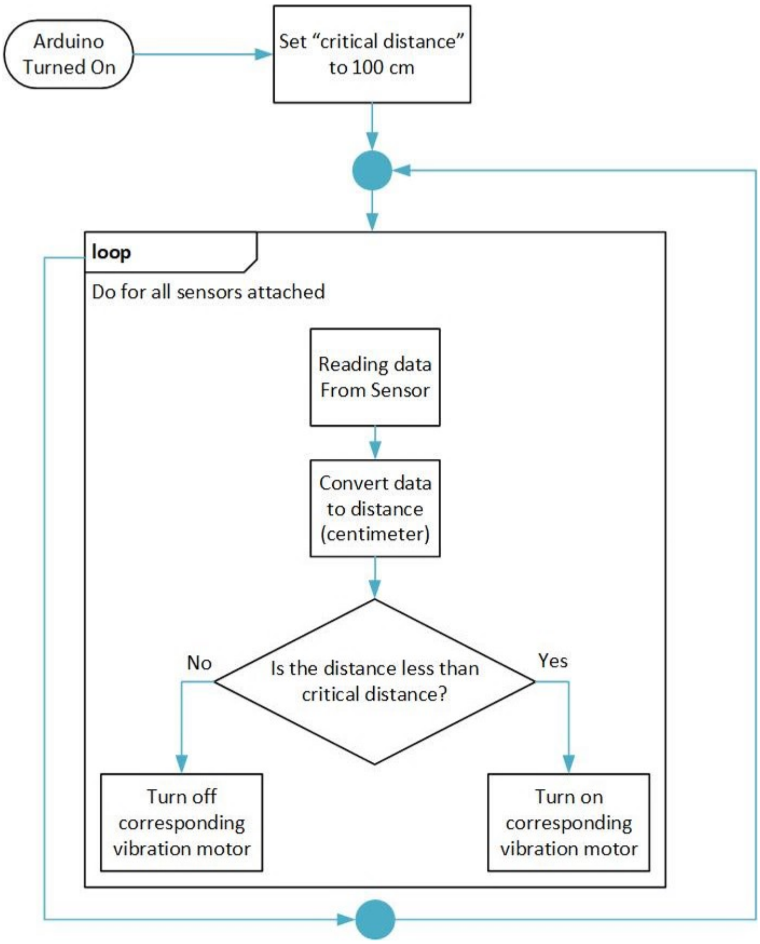


Figure 3.22: Flowchart of of *HaptiGuard* version 2

Chapter 4

HaptiGuard - User Study

After HaptiGuard's prototype was created, we conduct a user study to test its performance and usage. The objective of this user study is to measure HaptiGuard's precision, accuracy, and detection percentage when used by people in real condition. Another aim of this user study is to compare two different location of the sensor: when wore on the wrist and wore on the arm. Participant's comfortability and disruptiveness when wearing HaptiGuard is also measured to determine which sensor location is better. The result will help us determine whether HaptiGuard will be useful as an aid for deaf people.

4.1 Objective and Aim of User Study

The main goal of this user study is to evaluate overall *HaptiGuard*'s system. The result will determine whether as a system, *HaptiGuard* is able to reduce human's blind spot and therefore will be useful as an aid for deaf people. And as a prototype system, *HaptiGuard* needs to be used and evaluated by normal people.

4.2 Variables

As discussed earlier, these are the variables that we use and defined when evaluating *HaptiGuard* system:

4.2.1 Independent Variables

We define 3 variables as independent variables:

- Sensor Location: 2 levels: Arm and Wrist. Based on our research question on which position is better for the sensor.
- Incoming Direction: 5 levels: 3 main direction: Front, Middle, Back; 2 intersection direction: Middle-Front and Middle-Back. Based on the amount of sensor we put in the system and its intersection points.
- Speed: 3 levels: Standing Still, Slow Walking, and Fast Walking. Based on possible activities done when people are walking outdoor.

4.2.2 Dependent Variables

The dependent variables are the main points of the evaluation, and we define 4 dependent variables:

- Detection Point: The percentage of participant detect something is coming towards them before the object become too close.
- Precision Point: The percentage of participant correctly guess from which direction the object is coming towards them.
- Comfortability Level: 5-point Likert scale of how comfortable participant is when wearing the sensor at specific location. Level 1 means very not comfortable and level 5 means very comfortable.

- Disruptiveness Level: 5-point Likert scale of how participant found the disruptiveness of the sensor at specific location. Level 1 means very disruptive, while level 5 means very natural.

4.3 Setup and Apparatus

We asked the participants to use *HaptiGuard* on a treadmill and identify from which direction the experimenter is coming towards them. The experimenter will walk from outside of *HaptiGuard*'s theoretical distance until they get close to the participant.

Because using deaf people in our user study could be dangerous, we asked for normal people to test this system instead. But, in order to mimic deaf people's condition, we block their ears with noise canceling earphones. After we conduct our pilot user study, we realized that just blocking participant's ears is not enough since participant still rely more on their eyes instead of the *HaptiGuard* system. Therefore, to ensure that participant didn't rely on their eyes, we blocked participant's left eye with eye-patch. We could also block participant's both eyes, but doing so will be dangerous because our experiment require participant to walk on a treadmill.

4.3.1 Hardware

- *HaptiGuard* prototype.
- A treadmill.
- A smartphone connected to noise-cancelling earphone.
- An eyepatch.
- A portable distance marker. Its size is 2 * 1 meters, containing 5 lines with 50 cm gap between lines (for illustration see figure 4.1). In our case, the distance marker is put on top of a picnic carpet (figure 4.2)

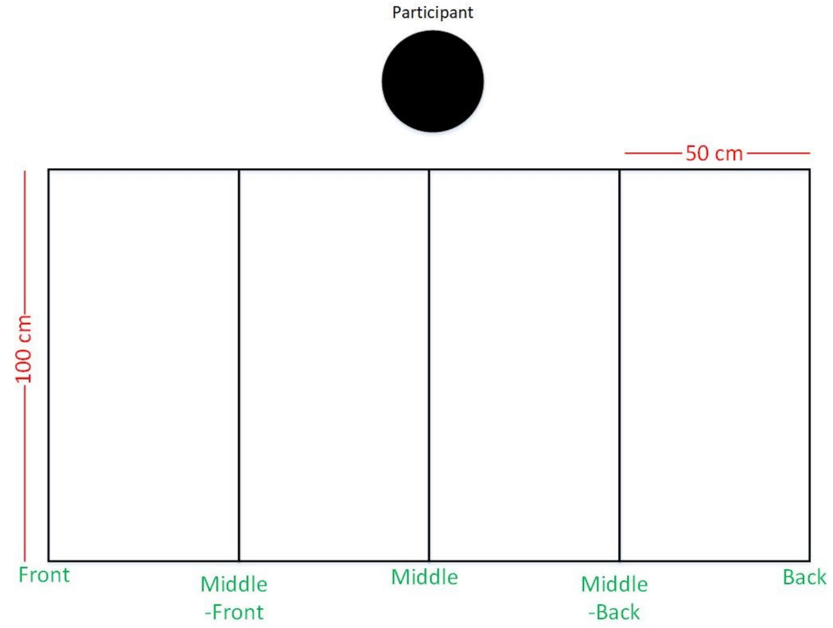


Figure 4.1: Distance marker's size and position

- Sets of task-sequence, counter-balanced using Latin square between each task-sequence. One task-sequence contains the order of sensor location, speed, and incoming direction for each participant. For example, see figure 4.3.

4.3.2 Software

- Any music player software. Should be installed in the smartphone. Music should be played throughout the experiment to dilute participant's hearing.

- Any software that plays a bell or an alarm. Should be installed in the smartphone. The bell sound is played by Experimenter before Experimenter begin to approach participant from new direction. That way participant is notified every time a new task began.

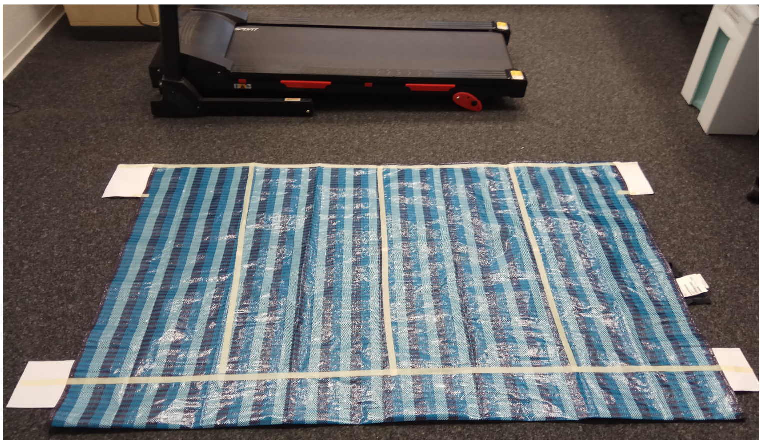


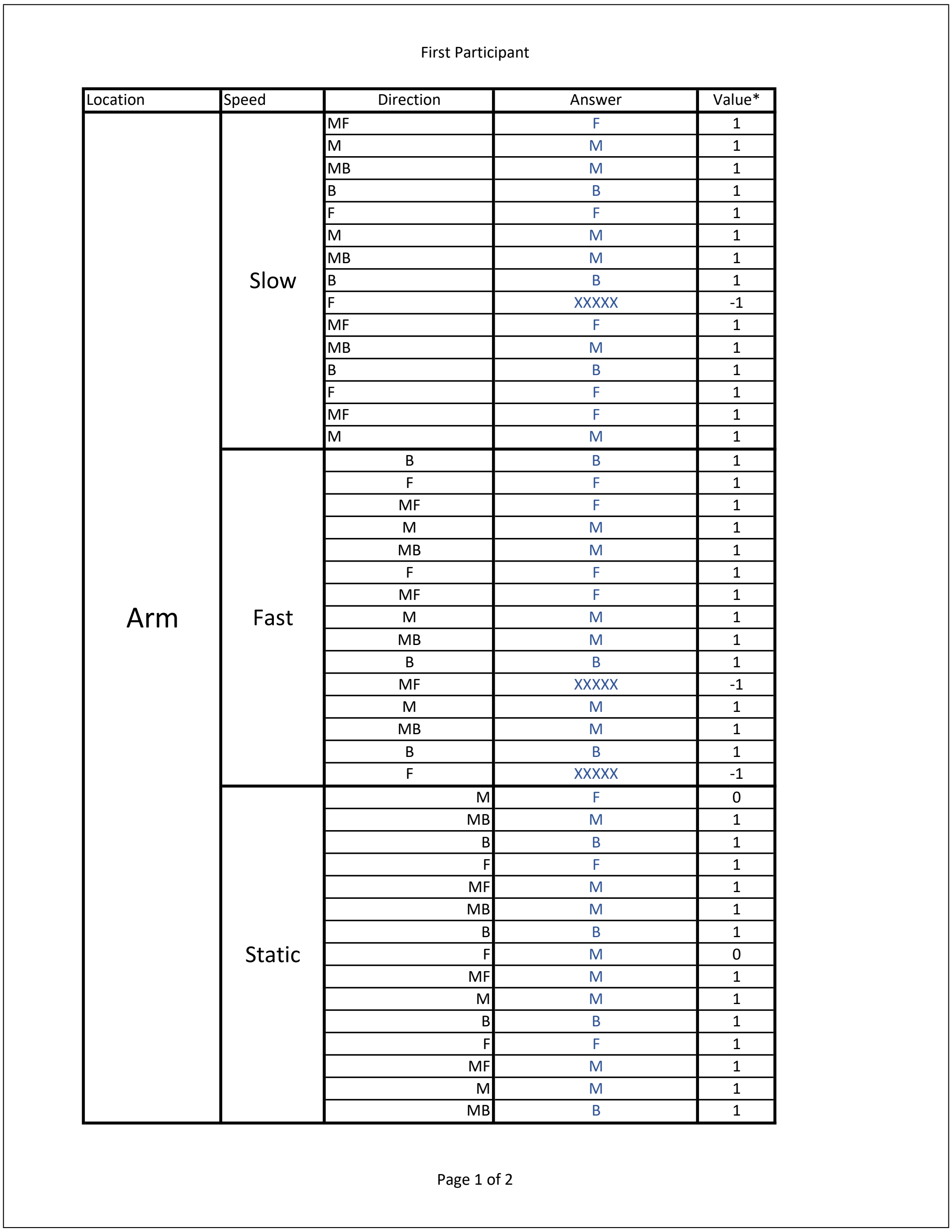
Figure 4.2: Picnic carpet with distance marker for our user study.

4.3.3 Setup

Participant will firstly wear eye-patch, noise-cancelling earphone, and *HaptiGuard* prototype. Then participant place themselves on top of the treadmill. Experimenter then adjust the distance maker so its position is in-line with participant's position (see figure 4.1). Experimenter make sure that the earphone is playing the music and playing the bell sound.

4.4 Research Questions

- How high is the overall detection point of *HaptiGuard*?
- How high is the overall precision point of *HaptiGuard*?
- Which position is better for the sensor? Which position have a better value in term of detection point, precision point, comfortability level, and disruptiveness level?
- Is *HaptiGuard* a useful aid for deaf people?



First Participant

Location	Speed	Direction	Answer	Value*
Arm	Slow	MF	F	1
		M	M	1
		MB	M	1
		B	B	1
		F	F	1
		M	M	1
		MB	M	1
		B	B	1
		F	XXXXX	-1
		MF	F	1
		MB	M	1
		B	B	1
		F	F	1
		MF	F	1
		M	M	1
	Fast	B	B	1
		F	F	1
		MF	F	1
		M	M	1
		MB	M	1
		F	F	1
		MF	F	1
		M	M	1
		MB	M	1
		B	B	1
		MF	XXXXX	-1
		M	M	1
		MB	M	1
		B	B	1
		F	XXXXX	-1
	Static	M	F	0
		MB	M	1
		B	B	1
		F	F	1
		MF	M	1
		MB	M	1
		B	B	1
		F	M	0
		MF	M	1
		M	M	1
		B	B	1
		F	F	1
		MF	M	1
		M	M	1
		MB	B	1

Page 1 of 2

Figure 4.3: Example of a task-sequence

4.5 Study Tasks

Experimenter is in the same room with participant. Every participant's answer is noted manually by experimenter. Experimenter follows the order described in task-sequence for each participant to determine sensor location, speed, and incoming direction.

1. Experimenter explains briefly regarding the study setup, research question, and experiment procedure.
2. Experimenter leads participant to the treadmill. Participant then asked to walk in the treadmill and decide their preferred slow walk and fast walk speed.
3. Experimenter puts eye-patch and noise-cancelling earphone to participant.
4. Main Study:

   [a] Experimenter put *HaptiGuard* to participant. The sensor should be placed according to task-sequence.

   [b] Experimenter explains and demonstrate three possible output of *HaptiGuard*: Front, Middle, and Back. Experimenter also instruct participant to speak out loud which input they feel throughout the experiment.

   [c] Participant familiarize itself with *HaptiGuard*'s output.

   [d] According to task-sequence, experimenter asked participant to perform certain walking speed.

   [e] According to participant's position, experimenter adjust the distance marker.

   [f] Experimenter inform participant that the experiment will begin.

   [g] According to task-sequence, experimenter will walk towards participant from certain incoming direction. Between each task, experimenter will sound the bell to inform participant that new task began.

[h] Repeat step d – g until participant perform all three of walking speed.

5. Repeat step 4, but with different sensor location.
6. After all task in task-sequence is finished, experimenter removed the eye-patch, earphone, and *HaptiGuard* from participant.
7. Experimenter asked participant to fill the questionnaire provided regarding demographics, comfortability level, and disruptiveness level.

4.6 Experimental Design

The order of sensor positions, speeds, and incoming directions for each participant is counter balanced using Latin Square. For each position, participant will do 3 speeds. For each speed, each incoming direction will be repeated 3 times. The diagram of experimental design can be seen in figure 4.4

- Main = 2 sensor positions x 3 speeds x 5 incoming directions x 3 repetitions = 90 tasks per participant.
- Total = 5 participants x 90 Main tasks = 450 tasks.

4.7 Participants

We recruited 5 participants aged 25 – 30 years old. Consists of 3 females and 2 males. 2 used wearable technology and 1 have minor hearing impairment. Between participants, the average slow walking speed is 1.82 km/h and the average fast walking speed is 3.32 km/h.

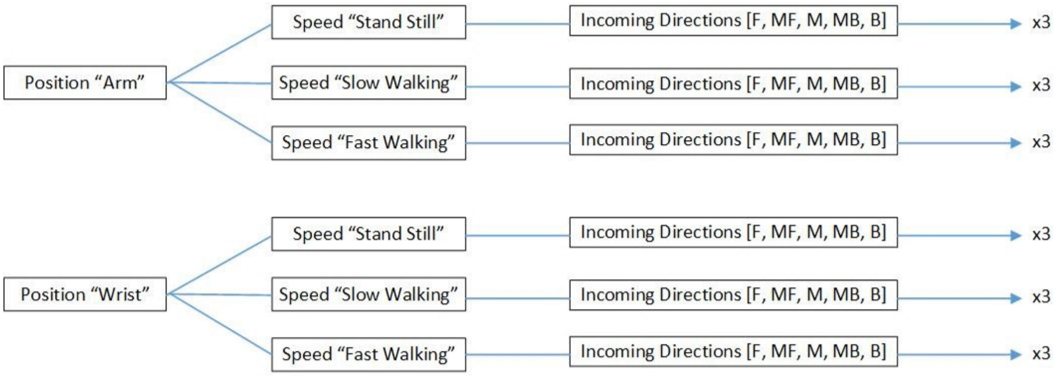
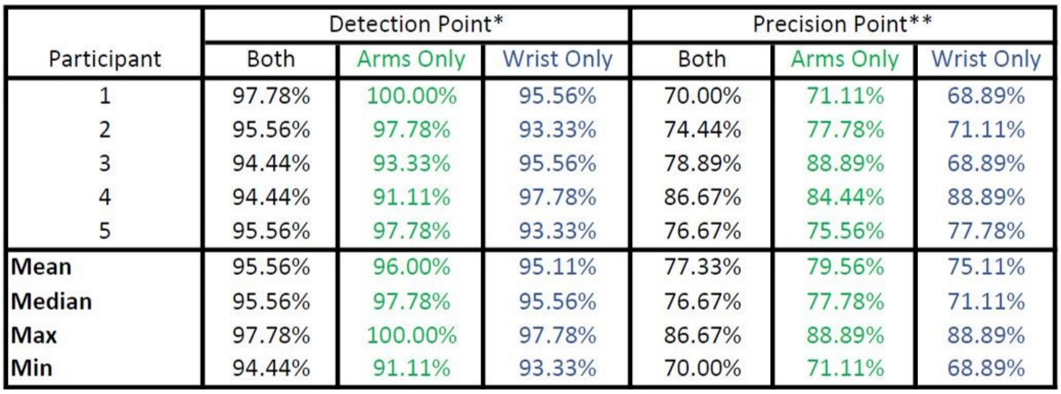


Figure 4.4: Diagram of experimental design.



Participant	Detection Point*			Precision Point**		
	Both	Arms Only	Wrist Only	Both	Arms Only	Wrist Only
1	97.78%	100.00%	95.56%	70.00%	71.11%	68.89%
2	95.56%	97.78%	93.33%	74.44%	77.78%	71.11%
3	94.44%	93.33%	95.56%	78.89%	88.89%	68.89%
4	94.44%	91.11%	97.78%	86.67%	84.44%	88.89%
5	95.56%	97.78%	93.33%	76.67%	75.56%	77.78%
Mean	95.56%	96.00%	95.11%	77.33%	79.56%	75.11%
Median	95.56%	97.78%	95.56%	76.67%	77.78%	71.11%
Max	97.78%	100.00%	97.78%	86.67%	88.89%	88.89%
Min	94.44%	91.11%	93.33%	70.00%	71.11%	68.89%

Figure 4.5: User study result: detection and precision point

4.8 Results

Detection Point

To measure detection point, we give score '1' when participant detects an incoming object and give answer before experimenter get too close to participant. If participant doesn't give answer at all or answers when experimenter is already too close, we give score '0'. We total the score for each person, and then divide it by the number of tasks for one person (90 tasks). However, detection point for each sensor location is divided by the number of tasks for that particular location (45 tasks).

From figure 4.5, we can see that the average detection point of *HaptiGuard* is 95.56%. The range of detection point is between 94.44% (minimum value) until 97.78% (maximum value).

If we compare the detection point between two sensor locations, the difference is not that striking. The average detection points when the sensor is located on arms is 96%. While when the sensor is located on wrist is 95.11%. The range when the sensor is located on arms is wider, from 91.11% (minimum) until 100% (maximum). While the range when the sensor is located on wrist is narrower, from 93.33% (minimum) until 97.78% (maximum).

Using one-way ANOVA, we found that the F-value = 0.235, F-critical = 5.317, and p-value = 0.640. F-value is less than F-critical and p-value is bigger than 0.05. Therefore, we accept the null hypothesis. There's no significant difference in detection point between two sensor locations.

Precision Point

To measure precision point, we give score '1' for each correct answer and score '0' for each incorrect answer. We total the score for each person, and then divide it by the number of tasks for one person (90 tasks). However, precision point for each sensor location is divided by the number of tasks for that particular location (45 tasks).

What we deemed as incorrect answer is when participant's answer is not the same with incoming direction. As well as when the participant didn't answer at all or answers when the experimenter is already too close to participant. Otherwise, the category for correct answer is when participant's answer is the same with experimenter's incoming direction. However, from our pilot user study, we found out that it's hard to guess intersection area correctly since *HaptiGuard* only have three outputs: Front, Middle, and Back. Therefore, if the incoming direction is from intersection area (Middle-Front or Middle-Back), the correct answer is the corresponding main direction. In this case, if the incoming direction is 'Middle-Front', the correct answer is 'Middle' or 'Front'. And if the incoming direction is 'Middle-Back', then the correct answer is 'Middle' or 'Back'.

As displayed in figure 4.5, the average precision point for *HaptiGuard* is 77.33%, with range from 70% (Minimum) until 86.67% (maximum).

The comparison of precision point between two sensor's locations doesn't show much difference as well. The average for arms is 79.56% while for wrist it's 75.11%. The range for arms is between 71.11% (minimum) until 88.89% (maximum. While the range for wrist is 68.89% (minimum) until 88.89% (maximum). Using one-way ANOVA, we found F-value = 0.803, F-critical = 5.317, and p-value = 0.396. Since F-value is less than F-critical and p-value is bigger than 0.05, then we accept null hypothesis. There's no significant difference in precision point between two sensor locations.

Comfortability Level

The comfortability level is using 5-point Likert scale with level 1 means very not comfortable and level 5 means very comfortable. Like can be seen in figure 4.6, the average comfortability level between arm and wrist is completely the same at 3.8. The range is a little bit difference, with arm's minimum comfortability is at 2, while wrist's comfortability is at 3. Both have the same maximum though at 5. The modus for arm is 4, while for wrist the modus is both 3 and 4.

Participant	Comfortability		Disruptiveness	
	Arms Only	Wrist Only	Arms Only	Wrist Only
1	2	3	2	3
2	4	5	2	1
3	4	4	2	2
4	4	4	4	1
5	5	3	5	3
Mean	3.8	3.8	3	2
Modus	4	3	2	3
Median	4	4	2	2
Max	5	5	5	3
Min	2	3	2	1

Figure 4.6: User study result: comfortability and disruptiveness level

With one-way ANOVA, we try to compare both sensor location. F-value = 0, F-critical = 5.31, and p-value = 1. Again, F-value is less than F-critical and p-value is bigger than 0.05. So, we accept null hypothesis that stated that there's not much significant difference on comfortability level between two sensor locations.

Disruptiveness Level

Disruptiveness level is 5-point Likert scale with level 1 means very disruptive and level 5 means very natural. In figure 4.6, the arm has better average disruptiveness level at level 3 in comparison with the wrist at level 2. The range is quite different as well. The arm's range is between 2 (minimum) until 5 (maximum). In contrast, the wrist's range is between 1 (minimum) until 3 (maximum). However, the modus for wrist is higher at level 3, in comparison with the arm at level 2.

Using one-way ANOVA, we again found that there's no significant difference between two sensor locations. F-value = 1.67, F-critical = 5.31, and p-value = 0.23. F-value is less than F-critical and p-value is bigger than 0.05 so we accept null hypothesis.

Observation

Throughout the study, experimenter takes notes on any unusual things that happen outside of experiment protocol. These notes are not related to the study's variables, but may be useful to help making conclusion of the study.

- *HaptiGuard*'s prototype is too big for all female participant since their arm and wrist is very tiny in comparison with male. Several adjustments were done in order to equip *HaptiGuard* to female participant.
- Some people wears thick long sleeves, and the sleeves reduce the vibration given by *HaptiGuard*.
- All female participant has tiny wrists so there's not enough space to place three sensors. The sensors had to be put really close together in order to fit on their wrist. It's hard as well to fix the sensor's position when used on the wrist.
- Some participant put their hand on the treadmill's rail when walking fast. When the sensor is equipped on the wrist, it makes the sensors facing participant's front instead of participant's side. Several adjustments on the sensor's position and distance marker has been done in order to keep the study going. However, the same problem doesn't happen when the sensor is equipped on the arm.
- Some participant moves their hand when walking fast. When the sensor is equipped on the wrist, it made participant detect something other than the experimenter that comes towards them. The same problem doesn't happen when the sensor is equipped on the arm.
- Some participant is tall. And when doing the study, they also stand on the treadmill. When the sensor is equipped on the arm, the sensor's location become

too high to detect experimenter. To adjust this trouble, the experimenter is raising his hand when coming towards participant. The same problem doesn't happen when the sensor is equipped on the wrist.

Chapter 5

Summary and future work

We take conclusions from user study results and discuss future works. We also evaluate the HaptiGuard prototype and what could be improved for better results.

5.1 Summary and contributions

5.1.1 HaptiGuard Effectivity vs Precision

From the user study result in 4.8, we can see that *HaptiGuard* have average detection of 95.56% and its average precision is 77.33%. Using t-test for paired two means, we found that t-Statistic = 5.54, t-Critical = 2.77, and p-Value = 0.005. Since t-Stat is bigger than t-critical and p-value is less than 0.05, then we reject null hypothesis: there's significant different between *HaptiGuard*'s effectivity and precision.

HaptiGuard is effective to detect an object coming towards user, as can be seen by its high detection point. However, since its precision point is quite low, user can't correctly guess from which direction the object is coming.

In regard to its precision, we have some hypothesis factor about why the precision is not too good. In the future works, these factors could be improved in order to increase the precision point and give better feedback to users.

First factor, feedback position. Most participant said that they have difficulties differentiating between front and back output. However, they have no difficulties detecting middle output. The faster participant walks and more movement is made by the arm, the harder it is for participant to differentiate between them. Middle output on the *HaptiGuard* is separated vertically with front and back output. While front output and back output is separated horizontally between them. Looks like vertical separation on the arm is easier to be detected rather than horizontal separation. Another research in the future to differentiate which separation type is better and how to properly locate output for each sensor is needed.

Second factor, the size of the arm. Female participants have lot smaller arm and wrist than male participant. In the observation part, we already stated that some participant's wrist is too small for three sensors. The same happens for the feedback part: the participant's wrist is too small for front and back output to be separated completely. This made participant had difficulties differentiating them. Another attempt needs to be made in order to make the feedback more differentiable.

Third factor, the type of clothes used by participant. Some participant is wearing long sleeves, and because *HaptiGuard* is equipped over the clothes, its feedback is sometimes too little to be differentiated by participant. They did feel the vibration, but it's hard to tell which part is vibrating. In the future, the feedback part perhaps could be embedded in the clothes instead of wore over the clothes. This way the feedback will be felt directly by participant's skin. Otherwise, perhaps another form of feedback that give more precise output could be used.

Overall, as a system, *HaptiGuard* is more suitable as a detection system that warns user that something is coming from their side. User then need to move their head to precisely measure from which direction the object is coming and act accordingly.

5.1.2 Sensor Location Arm vs Wrist

From the user study result in 4.8, we have compared two sensor locations against four criteria: detection point, precision point, comfortability level and disruptiveness level. Using one-way ANOVA analysis for each criterion, we have showed that there's no significant difference between putting the sensors on the arm or on the wrist.

However, from our observation, we have different opinion. First, we noticed that some participants wrist (especially female participant) is tiny. *HaptiGuard*'s sensor part consist of three ultrasonic sensors and all three sensors could hardly fit on their wrist. Since the arm naturally bigger than wrist, the same problem doesn't happen when the sensor is placed on the arm.

Second, participant's habit makes the sensor doesn't work the way they are designed. For example: when walking, some participant tends to move their whole arm while some put their hand on the treadmill's hand grips. When the sensor is placed on the arm, these habits doesn't make many difference since the arm position is stable: always on the side of participant. However, when the sensor is placed on the wrist, these habits make wide wrist movement that cause the sensor not functioning properly. In several occasions the sensor detects something other than the experimenter, and in another occasion the sensor is facing participant's front instead of participant's side.

Therefore, for *HaptiGuard* only, it's better to put the sensor on the arm instead of the wrist. Since *HaptiGuard*'s design require a stable position of its sensor, and the arm provide this stability better than the wrist.

5.1.3 HaptiGuard as an Aid for Deaf People

We already conclude in 5.1.1 that *HaptiGuard* is suitable as a detection system. *HaptiGuard* user will be notified immediately whenever an object is coming towards them. But since user can't determine exactly from which direction the object is coming, user need to move their head to see the object's direction and act accordingly.

Since deaf people doesn't have problem of moving their head or seeing the object, we conclude that *HaptiGuard* should be useful as an aid to help deaf people detecting object coming from the side.

Of course, to validate this claim, another research in the future should be done. *HaptiGuard* should be worn by deaf people, and the user study (with several revision in its detail) needs to be conducted again. Unfortunately, because safety and language reason, we didn't conduct the user study with deaf people. But since we conditioned the participant of our user study to mimic deaf people, the result should not show too much different.

5.2 Future work

The first future work would be of course, a research that test *HaptiGuard* when used by deaf people. For our study, for safety reason, we simulate outdoor situation in order to keep user's safety. Using our result as a base, another research with deaf people on real outdoor situation should be held to further investigate whether *HaptiGuard* could be used in real world situation.

When we built the prototype, we were more focused on making the prototype modular. Our prototype was meant to be used in the user study, therefore it has to be able to be used by different kind of people. Therefore, there are a lot of things could be improved for *HaptiGuard*. It would be easy to shrink the technology and improve the armband altogether for another study. Below we will discuss about what kind of improvement that could be done to *HaptiGuard*.

For now, the prototype contains of two parts because there's no space left on the armband. In the future, an improvement is needed so only one part could remain. In order to reduce the space, there are some things that could be done. For example, smaller arduino could be used. And since now we know that we will use *HaptiGuard* as warning system, then there's no need to build adjacent formation between output and input. The vibration motor as output could be placed anywhere on the armband and its amount could be varied according to the strength of vibration needed. Smaller battery could also be used in order to reduce the space used.

As technology evolves, in the future there will be better sensors that could be used to improved *HaptiGuard* itself. For example, when this report was written, there's new LIDAR sensors VL53L1X that just released and it's stronger in comparison with its predecessor, VL53L0X. VL53L1X could detect until 1 meter and have adequate field of view. Adding this sensor to *HaptiGuard* will be very useful.

The sensor that is used in *HaptiGuard* will become obsolete and out-to-date after several years as well. Smaller and more effective sensor could be used to replace HC-SR04 that is used in *HaptiGuard*. Not only it will reduce the space used, perhaps the angle of each sensor will be wider so only one sensor is needed to reach the same angle as *HaptiGuard* today.

Improvement could also be done on the armband. The armband that we used in *HaptiGuard* is a regular armband made from synthetic polymer (polyamide). The problem with this armband is, it's hard to attach anything to its surface. Because of that, in our prototype we have to sew all related parts to the armband. This is a factor that we didn't thought will affect the creation of prototype. If the armband used is created from different material, this problem could be eased. An idea is creating the armband using E-textiles or smart garments. With smart garments, all the electronic component could be compressed inside the armband and will make *HaptiGuard* looks a lot better.

Another study in the future could also be done to investigate more about the relation and difference these two sensor locations. We already showed that the sensor locations don't impact effectivity, precision, comfortability, or disruptiveness. Therefore, future study could focus more on another factor such as sensor locations with user's habit, or wrist size with sensor type. The study could also come up with new design that always faces to one direction regardless of user's movement.

Even though *HaptiGuard* is aimed for deaf people, it would be great as well if it could be used by blind person. However for blind person, the user should also be informed precisely about the direction of incoming object. And in that case, *HaptiGuard*'s output should be improved so user correctly guess the incoming direction.

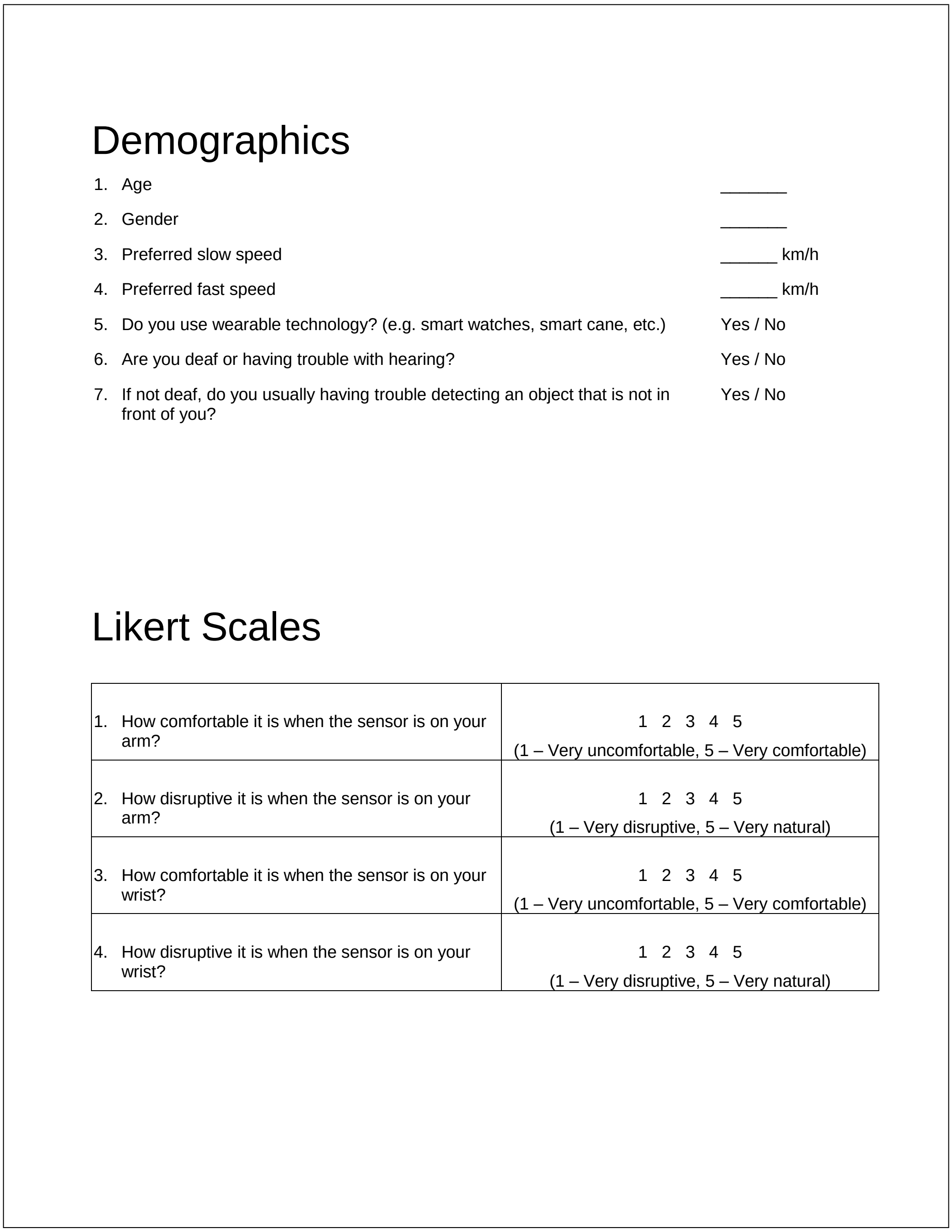
Further research should be done to completely erase human's blind spot and create 360° detection area. An interesting approach would be to combine *HaptiGuard* with Lee et al. [2016]'s *LaneMate*. *HaptiGuard* will reduce the blind spot by 90° on the right and left side, while *LaneMate* will reduce the blind spot on the back side. This research will be useful for deaf people as well as blind people.

Appendix A

Appendix for HaptiGuard's user study

A.1 Participant's Questionnaire

We asked participant to fill questionnaire like shown in figure A.1.



Demographics

1. Age _______
2. Gender _______
3. Preferred slow speed ______ km/h
4. Preferred fast speed ______ km/h
5. Do you use wearable technology? (e.g. smart watches, smart cane, etc.) Yes / No
6. Are you deaf or having trouble with hearing? Yes / No
7. If not deaf, do you usually having trouble detecting an object that is not in front of you? Yes / No

Likert Scales

1. How comfortable it is when the sensor is on your arm?	1 2 3 4 5 (1 – Very uncomfortable, 5 – Very comfortable)
2. How disruptive it is when the sensor is on your arm?	1 2 3 4 5 (1 – Very disruptive, 5 – Very natural)
3. How comfortable it is when the sensor is on your wrist?	1 2 3 4 5 (1 – Very uncomfortable, 5 – Very comfortable)
4. How disruptive it is when the sensor is on your wrist?	1 2 3 4 5 (1 – Very disruptive, 5 – Very natural)

Figure A.1: *HaptiGuard's* questionnaire

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