

WHEELCHAIR DRIVING AID

Submitted
to
David Knox

by

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This report will outline the design process used to create a solution to the given problem of designing a wheelchair driving aid.

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ABSTRACT

The problem of mobility-related disabilities is increasingly prevalent in the populations of the world. In Canada alone, 7.2% of Canadians are reported to have mobility-related disabilities. With 20.5% of these people being elderly, it can be expected that the prevalence of these related disabilities will only continue to increase with the retirement of the “baby-boomer” generation. Furthermore, of the people afflicted with mobility-related disabilities, 8 of 10 use assistive devices, such as wheelchairs.

As the number of wheelchair users increases, so will the prevalence of related issues regarding their daily operation. According to hospital employees at St. Vincent’s hospital, wheelchair operators have problems in their general spatial awareness which impacts their ability to avoid obstacles. This therefore can lead to injury and other damages.

In order to design a system for a wheelchair that indicates the surroundings to user with limited spatial awareness and alerts the user to obstacles, we decided to use a design thinking process. The first stage of this project therefore entailed interviewing the client in order to formulate an understanding of both their problem and needs regarding a solution. From this a problem was defined in the next stage by forming a problem statement, benchmarking and defining metrics and target specifications. In the next stage this information was used to form design criteria and ideate based on this. To create the final solution, individual solutions were formed and compared against the design criteria using a design matrix and then the best of the individual concepts were compared in the same way. Although close to the client’s wants, due to client feedback we added extra sensors to this design to further solve the problem. From here, low-fidelity prototypes were built and tested until a final high-fidelity prototype was built. This final model was tested against the criteria and client.

During the secondary prototyping process, the work was divided between two main teams based on program expertise. The computer and software engineering partners, Ivan and Quang-Vinh, were responsible mainly for the completion of the electronic systems while the mechanical engineering students, Nathalia and Raveen, were responsible mainly for the structural subsystems. Upon completion of individual tasks, the system was assembled.

In future iterations, detailed schematics of both the complete system as a whole as well as wiring would be made to improve aesthetics, reliability, ease of use, and coordination. Also, higher quality 3-D printer filament and wires to improve reliability, usability, and quality of the product. This would require regular meetups between teams to track progress, discuss issues, update schematics and run preliminary testing of the system together to foresee problems or make improvements.

The solution iterated by this design group addresses the issue of creating a wheelchair driving aid to increase a user’s spatial awareness and their ability to avoid obstacles.

1.0 Introduction

The problem of mobility-related disabilities is increasingly prevalent in the populations of the world. In Canada alone, 7.2% of Canadians are reported to have mobility-related disabilities. With 20.5% and of these people being elderly, it can be expected that the prevalence of these related disabilities will only continue to increase with the retirement of the “baby-boomer” generation. Furthermore, of the people afflicted with mobility-related disabilities, 8 of 10 use assistive devices, such as wheelchairs.

As the number of wheelchair users increases, so will the prevalence of related issues regarding their daily operation. According to hospital employees at St. Vincent’s hospital, wheelchair operators have problems in their general spatial awareness which impacts their ability to avoid obstacles. This therefore can lead to injury and other damages.

This project group was tasked with seeking a solution to this problem by designing a system that will aim to aid wheelchair users in being aware of objects in their surroundings to make wheelchair operation easier and safer. The creation of this system will be important to both users and to those around them, such as family and hospital employees, as it will increase their ability to move around independently and decrease their reliance on the assistance of others.

The design created to address this problem utilises an audio-visual system which aims to increase spatial awareness with the combined use of a camera system that displays the environment to the rear of the user and a proximity sensor system that alerts the user to obstacles to the rear, sides and front. The system was also designed to be ergonomic and user-friendly with the hinged display arm that is adjustable to the user. Furthermore, with the use of 3D printing technology, the cost per unit has been decreased and the driving aid is therefore more affordable.

The following report presents the process in which this system was designed and built and then concludes with a discussion regarding future changes that would improve the product and user experience.

2.0 Design Process Model

When creating a project plan, it is important to consider the design process, or stages in which a design will be formulated. In developing this product, our project group used a design thinking process, which aims to use an empathetic, iterative waterfall-staged course to develop a solution. This was selected as it places an emphasis on empathetic design which was important in producing a design that worked for our specific client.

The design process took place in five main stages which will be explored through this report:

- Empathise
- Define
- Ideate
- Prototype
- Test

3.0 Design Process Stage 1: Empathise

The first step in the design process was to define the problem based on an understanding of both the solution and whomever it is being generated for. This was achieved first through an interview with the client, whose statements were then analysed to formulate an idea of the needs.

Our client, Bocar N'Diaye is a technician at St. Vincent's hospital, who has years of experience with the general patient. He is therefore able to generally empathise with the population that will make the most use of our design. From this interview, we were able to narrow down his most important statements that pertain to which types of people will be using the device, the limitations they have that need to be addressed by this device and what the solution needs to contain to address these problems.

The following presents a collection of the information presented at the interview:

Topic 1: Types of disabilities and limitations they give the patient:

- “Obviously when someone is in a wheelchair it means they do have physical disabilities, not being able to walk, so then your option is how you can make them more mobile”.
- “It’s not always a low extremity disability, it could be upper body extremity disabilities and then based on the Occupational Therapist and Physical Therapist assessment they look at how to control a wheelchair and where the abilities they can use, using hands - use a joystick for that, or use a puffing kind of blow and puff and sucking straw to control wheelchair.”
- “So with the physical disability, let’s say driving, even though some people could use a joystick, you may notice that they don’t have full control of the joystick using their fingers. They would use, maybe there is some issues using your fingers correctly, to hold on or grip. They call them fine motor skills, they may lack that. They would use gross motor skills like thumbs, wrist or fist to push the joystick. If they pass that test at least they have control but that creates a bit of an issue with driving so you don’t have full control of fine motor skills so sometime when you use big movements like going into small spaces or having to driving slowly to get around a computer table or to drive through a door you cannot do full speed and have to use small movements. So this is where accidents would happen.”
- Some patients when using a joystick have issues with steering. Eg. When a patient was moving his wheelchair with the joystick his hand got too close to the sink and he scraped his hand. Some patients are also on medication and are given too much so they are spaced out and may have issues with awareness.
- Patients also have issues going through doorways and along the sides of hallways - you can see the scraped paint in the halls that is always being re-painted.
- “Also when going on an elevator, pushing a button or being close enough to the button to press it. Any environment, it could be home or even going to the mall, or going on a bus, all of these are where accidents possibility of obstacles and hitting something. “
- “Augmented vision, something that could help with limited field of vision. “

Topic 2: Solutions

- “If you have something that aids, that isn’t too distracting but could aid, help to see better, know where end of wheelchair is, all those would help for sure.”
- “For me, because I try to be more looking forward, some people want something more practical like walking and all that, but I am trying to see the future of wheelchairs would be and how we could improve an existing one. I want something smart, like a smart wheelchair, one that would warn you and even avoid obstacles and accidents.”
- It is important that the design doesn't compromise the safety of the wheelchair. The frame therefore can't be meddled with (no drilling, etc) and the durability of the chair can't be compromised (can't break it or cause it to break).
- “We want them to be more independent to go home. But to go home you have to be showing that you are ready for it or have the capability to move around, go around, be mobile. Sometimes that is what hinders some clients not to go home. “

Benchmarking

- “Apparently there are some things, but they aren’t widely used, perhaps some add on cost or some have to buy your own.”
- “I’ve seen a flag, you know, a red kind of flag, at the back of the chair and I think it kind of helps the wheelchair user in some way, I don’t know if it is height or the positioning.”
- “People use mirrors, wheelchair mirrors. I don’t know if Phil showed you the mirror they use, but people kind of don't like it. The one we have isn’t well used, but some people may need it. I’m not saying to rule it out but I’m just saying we have them apparently to help people see when they are backing out or something. But I don’t know how well it can be used. “
- “Those are some kind of aids, I haven't seen anything smart for the wheelchair. They probably exist.”
- “It is one of the reasons why i thought it would be a great idea to have some wheelchair aid because you see quite a bit of bumping and breaking. We have smart cars that do that, when you are backing out they have a sensor that warns you, the wheelchair costs almost like a car. “

Observations

- Although he doesn’t want to limit our designs so early on, Bocar was very interested in using technology, especially a camera. He frequently repeated this.

From these statements, we were able to create a list of needs specified by Mr. N’Diaye:

1. Make patients more independently mobile in a variety of environments both in and out of the hospital..
2. Allow patients to operate with limited fine motor skills in smaller spaces to perform more precise movements.
3. Help patients to avoid hitting obstacles and having accidents while operating a wheelchair.
4. Aid patients going through doorways, around corners and through hallways while avoiding walls.
5. Help patients with a limited field of view.

6. A driving aid that is out of the way when the wheelchair is operating.
7. Use of smart technology.
8. A system built around the frame to avoid interference with the structural integrity of the wheelchair.
9. A system complete enough for the hospital technicians to be able to put together and use/test afterwards.

4.0 Design Process Stage 2: Define

From the empathetic understanding of the client and their needs we were able to define the problem in which the final design would solve. The first stage in this definition process was the formation of a problem statement based off of the given information:

“Design a system for a wheelchair that indicates the surroundings to user with limited spatial awareness due to disabilities. This will use cost-efficient, “smart” technology to provide adequate warning to the consumer to avoid collisions.”

The next stage in the definition process was to benchmark existing designs which also aim to solve this problem and learn from them. The following presents the results of the research:

Design 1:

Here in this picture we can see a small mirror attached to one of the armrests of the wheelchair. This mirror will allow the patient to see objects behind them, similar to that of a rear view mirror in a car. Although this option allows a greater field of view there is no collision warning system and the actual field of view is not that effective.



Figure 1. Image of wheelchair user in first benchmarked design. (Mirror)

Design 2

Here in this picture we can see a display attached to one of the armrests of the wheelchair. This product does not have a camera connected to the screen however, the screen setup seems to be in an ideal and practical location on the wheelchair. We could use a similar set-up however for our project we will be using a manual wheelchair rather than an electric one shown to the left.



Figure 2. Image of wheelchair in second benchmarked design. (Smart Wheeler, 2014)

Design 3

In this picture we have what is a combination of proximity sensors that are connected to a automatic braking system. Although our wheelchair will not include the braking system, we will be including proximity sensors. One interesting idea from this design is that all of the wiring from the electronics is behind the seat. Therefore it is out of the way of the patient and cannot be accidentally tampered with.



Figure 3. Image of wheelchair in third benchmarked design. (SMP 2013)

Design 4

Lastly one of the product designs that we found was a manual wheelchair, that had a proximity sensor in front of the wheelchair. This was catered towards patients who have limited visibility. One of the setbacks to this design is that the wiring in in the way of the patient and could possible become a hazard. Additionally our initial project description addressed patients who could not see to the sides and towards the back portion of the wheelchair.



Figure 4. Image of wheelchair in fourth benchmarked design. (Short Range Sensor for Smart 2005)

After translating the client's, Mr. N'Diaye's, statements into a list of needs and benchmarking to see what products are currently available, we are able to determine a list of metrics that the design will incorporate. This set of precise descriptions based on current information are given in measured quantities:

Table 1. List of metrics.

Metric	Units	Description	Corresponding Need
Lifespan	Time - years	How long the product will last before replacement	1
Maintenance service	Time - months	How often to have a technician do a maintenance check on the system	1,7,9
Proximity sensor max distance	Distance - centimetres	The furthest distance that the proximity sensor can detect	2,3,4,5,6,7
Proximity accuracy	Error - +-cm	The error in measuring the distance	2,3,4,5,6,7
Product mass	Mass - kg	How heavy the entire system is	1,6,7,8
Range of view	Angles - degrees	The range of view from the camera, 360 degrees max	1,3,4,5,6,7
Cost	Money - dollars	The total cost of materials needed to make the product	1,5
Installation time	Time - minutes	How long it takes to install the product on a wheelchair	9
Screen size	Diagonal length - cm	The size of the screen which will display the camera view	1,3,4,5,6,7
Screen quality	Pixels x Pixels	Quality of image displayed by screen	1,3,4,5,7
Battery life	Time - hours	How long the system will function on one full charge	1,7

Table 1 displays the list of metrics used in the project, describes and lists their units and states their corresponding need.

Based on these metrics, we determined the target specifications for our designs:

Table 2. Target specifications.

Metric	Importance	Marginal value	Ideal value	Reason for choice
Lifespan (years)	3	>5years	>10year	Client will eventually be living independently at home. Should last a long time
Maintenance service (months)	3	>6months	>12 months	Wheelchairs are checked every year approximately, product should be around the same
Proximity sensor max distance (cm)	4	>100cm in rear <50 on sides	>200cm in rear <100 on sides	Should give earliest detection as possible Meets early warning system need
Proximity accuracy (+- cm)	5	<+- 30 cm	< +- 10 cm	Sensor should be most accurate as possible to give proper detection warning Meets early warning system need
Product mass (kg)	2	<10kg	<5kg	Should not be too heavy and create difficulty moving around in wheelchair
Range of view (degrees)	4	>160 degrees	>270degrees	Should at least be able to cover the back view. Would be ideal to cover back and sides Meets spatial awareness need
Cost (\$)	4	<100\$	<70\$	Must be implemented on several wheelchairs, should not be too expensive for hospital Meets cost-efficient need
Installation time (minutes)	2	<60 minutes	<20 minutes	Must be installed on several wheelchairs in hospital

Screen size measured diagonally (cm)	4	>14 cm <35cm	>18cm <25cm	Should be at least size of average phone display for those with impaired vision. Shouldn't be too big to be in the way
Screen quality (pixels x pixels)	4	>320p x 240 p	> 1280p x 720p	Should at least be able to make out obstacles. Ideal HD resolution for those with impaired vision
Battery life of system on one full charge (hours)	4	>6 hours	>8 hours	Long enough for a day's use

Table 2 displays the list of target specifications used in the project and ranks their importance as well as justifying the choice for the specification.

Upon interviewing Mr. N'Diaye it became clear that he wanted a design that was intuitive, long lasting, “smart” and user-friendly. His idea of the creating of a driving aid came from part of his forward thinking into accessibility and independence with the upcoming paradigm shift within the government, which he also made us aware of. This shift in population age is currently driving hospitals, including St. Vincent's, to shift from their current long term care structures to a system that will reduce the time patients are requiring to spend in the hospital. This is to both reduce cost for the government and to provide a more independent life for the (mainly) elderly customers, these things becoming essential to the aging “baby boomers”. This means that our design will have to be ergonomic and user friendly as, if it is implemented, it will be used and relied on a daily basis. Bocar was also very enthusiastic to incorporate “smart technology” into the design, such as the use of a camera and a screen for viewing obstacles behind the chair, as new technology often provides amazing solutions to everyday problems and is becoming more available and cost-efficient. The incorporation of technology into our designs therefore requires an integration into existing wheelchair platforms and operation and therefore cannot compromise the structure of the chair or impair the user's ability to steer the chair. The design will also have to provide reliable performance so that consumers can live independent lives without having to be under constant observation or use a gimmick that is not user friendly, thus adding to the problem. This means that when we went to analyse the needs of the product and any of our ideas and rough sketches, we had to take into consideration user friendliness, ergonomics, complexity (reduce it) and incorporate technology. After the interview, analysing the data, creating the requirements of the project and then entering the design phase to create ideas, we were able to harmonise all the concepts to create a solid foundation for a potential design and prototype.

Finally, we determined some of the constraints of our project and determined an order related to their importance:

1. Time: The design needed to be complete by Nov 29 giving us 2 and a half months.
2. Economics: The design was aimed to cost under \$100 inclusively.
3. Resources: This included any materials that could be acquired either through current or previous purchase, each member's current technical experience and knowledge, facilities including Makerspace and Brunsfield and the project manager Justine.
4. Compliance: No permanent changes to structural frame of wheelchair were to be implemented due to Health and Safety regulations concerning wheelchairs. To be in accordance with the Canadian Electrical Code by the CSA group, all electronics had to be made to code or purchased having already been made to code.
5. Useability: As the system must improve daily life and increase independence, the system must be easy to use.
6. Aesthetics: To help market our product we implemented some improvements to aesthetics.

5.0 Design Process Stage 3: Ideate

An important stage in the development of the product was concept design. These designs were based on a set of design criteria obtained through the research and creation of a problem statement, metrics and product specifications. Individually created designs were then evaluated and assessed based on the design criteria and a final concept was formed that either focused on one specific idea or a combination of many.

The first step in the ideation stage was determining design criteria. The following were determined based on the information collected in the Define Stage:

1. The system may help patients become more independently mobile both in and out of the hospital.
2. The system should provide users with an increase in their spatial awareness.
3. The system should provide warning of obstacles to the user.
4. The system may use cost-efficient, smart technology.
5. The system may last between 5 and 10 years.
6. The system may be maintained every 6-12 months.
7. The system should provide an indication to the user their proximity to objects on the sides and back.
8. The system may be up to 10kg in weight.
9. The system may give at least 170 degrees of visibility.
10. The system should cost a maximum of \$100.
11. The screen may be a resolution of 320x240 - 1280x720.
12. The screen may be a size of 14cmx18cm - 35cmx25cm.
13. The system should have a battery life of 8-8hrs.
14. The system must be built to attach to the existing chair and will not interfere with the frame.
15. The display may be located such that it does not get in the way of wheelchair operation.
16. The display maybe designed in such a way that it does not get in the way of the user getting in and out of the wheelchair.

17. The system should be user friendly.

Individual designs were ideated based on these criteria.

Nathalia's Solutions

Table 3. Nathalia's solutions I.





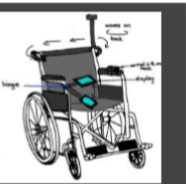
		Concepts									
Segment											
		1		2		3		4		5	
Selection Criteria	Weight (%)	Rating	Wtd	Rating	Wtd	Rating	Wtd	Rating	Rtd	Rating	Rtd
The system may help patients become more independently mobile both in and out of the hospital.	5	3	0.15	3	0.15	3	0.15	3	0.15	3	0.15
The system should provide users with an increase in their spatial awareness.	10	3	0.30	3	0.30	3	0.30	4	0.40	4	0.40
The system should provide warning of obstacles to the user.	10	3	0.30	3	0.30	3	0.30	3	0.30	3	0.30
The system may use cost-efficient, smart technology.	6	3	0.18	3	0.18	3	0.18	4	0.24	4	0.24
The system may last between 5 and 10 years.	2	3	0.06	3	0.06	3	0.06	2	0.03	2	0.03
The system may be maintained every 6-12 months.	2	3	0.06	3	0.06	3	0.06	2	0.04	2	0.04
The system should provide an indication to the user their proximity to objects on the sides and back.	10	3	0.30	3	0.30	3	0.30	4	0.40	4	0.40
The system may be up to 10kg in weight.	2	3	0.06	3	0.06	3	0.06	2	0.04	2	0.04
The system may give at least 170 degrees of visibility.	8	3	0.24	3	0.24	3	0.24	5	0.4	5	0.4
The system should cost a maximum of \$100.	5	3	0.15	3	0.15	3	0.15	4	0.2	4	0.2
The screen may be a resolution of 320x240 - 1280x720.	6	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18
The screen may be a size of 14cmx18cm - 35cmx25cm.	4	3	0.12	3	0.12	3	0.12	3	0.12	3	0.12
The system should have a battery life of 8-8hrs.	5	3	0.15	3	0.15	3	0.15	3	0.15	3	0.15
The system must be built to attach to the existing chair and will not interfere with the frame.	7	3	0.21	3	0.21	3	0.21	2	0.14	2	0.14
The display may be located such that it does not get in the way of wheelchair operation.	6	3	0.18	3	0.18	4	0.24	4	0.24	4	0.24
The display must be designed such that it does not get in the way of getting in and out of the wheelchair.	6	3	0.18	3	0.18	5	0.3	5	0.3	5	0.3
The system should be user friendly.	6	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18
Total Score			3.00		3.00		3.18		3.51		3.51
Rank			3		3		2		1		1
Continue?			N		N		N		Y		Y

Table 4. Nathalia's solutions II.






		Concepts									
Segment											
		1		6		7		8		9	
Selection Criteria	Weight (%)	Rating	Wtd	Rating	Wtd	Rating	Wtd	Rating	Rtd	Rating	Rtd
The system may help patients become more independently mobile both in and out of the hospital.	5	3	0.15	3	0.15	3	0.15	3	0.15	3	0.15
The system should provide users with an increase in their spatial awareness.	10	3	0.30	3	0.30	5	0.50	3	0.30	4	0.30
The system should provide warning of obstacles to the user.	10	3	0.30	3	0.30	5	0.50	5	0.50	5	0.50
The system may use cost-efficient, smart technology.	6	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18
The system may last between 5 and 10 years.	2	3	0.06	3	0.06	3	0.06	3	0.06	3	0.06
The system may be maintained every 6-12 months.	2	3	0.06	3	0.06	3	0.06	3	0.06	3	0.06
The system should provide an indication to the user their proximity to objects on the sides and back.	10	3	0.30	3	0.30	5	0.50	5	0.50	5	0.50
The system may be up to 10kg in weight.	2	3	0.06	3	0.06	3	0.06	2	0.04	2	0.04
The system may give at least 170 degrees of visibility.	8	3	0.24	3	0.24	3	0.24	4	0.32	4	0.32
The system should cost a maximum of \$100.	5	3	0.15	3	0.15	3	0.15	4	0.2	4	0.2
The screen may be a resolution of 320x240 - 1280x720.	6	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18
The screen may be a size of 14cmx18cm - 35cmx25cm.	4	3	0.12	3	0.12	3	0.12	2	0.08	3	0.12
The system should have a battery life of 8-8hrs.	5	3	0.15	3	0.15	3	0.15	3	0.15	3	0.15
The system must be built to attach to the existing chair and will not interfere with the frame.	7	3	0.21	3	0.21	3	0.21	3	0.21	3	0.21
The display may be located such that it does not get in the way of wheelchair operation.	6	3	0.18	3	0.18	1	0.06	4	0.24	4	0.24
The display must be designed such that it does not get in the way of getting in and out of the wheelchair.	6	3	0.18	5	0.3	5	0.3	5	0.3	5	0.3
The system should be user friendly.	6	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18
Total Score			3.00		3.12		3.60		3.65		3.69
Rank			5		4		3		2		1
Continue?			N		N		N		Y		Y

Table 5. Nathalia's solutions III.




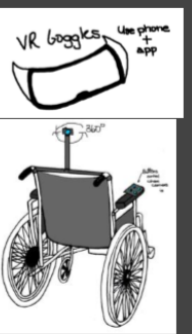
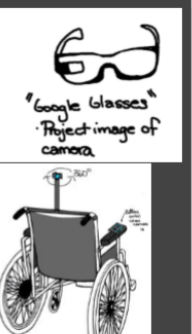

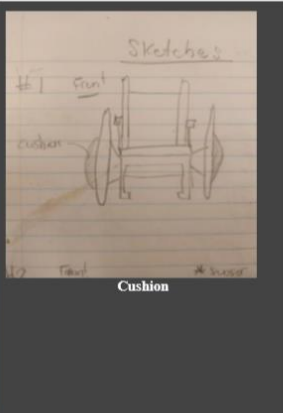
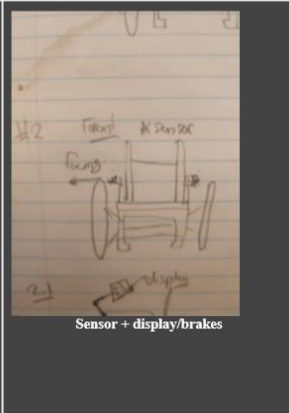
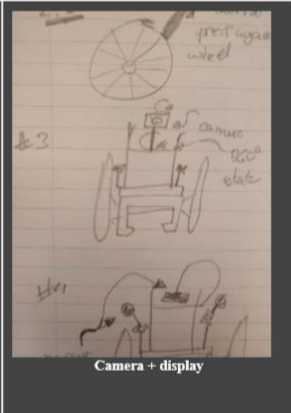
Concepts											
Segment											
											
		1		10		11		12		13	
Selection Criteria	Weight (%)	Rating	Wtd	Rating	Wtd	Rating	Wtd	Rating	Rtd	Rating	Rtd
The system may help patients become more independently mobile both in and out of the hospital.	5	3	0.15	2	0.1	2	0.1	4	0.20	4	0.20
The system should provide users with an increase in their spatial awareness.	10	3	0.30	2	0.20	2	0.20	5	0.50	5	0.50
The system should provide warning of obstacles to the user.	10	3	0.30	2	0.20	2	0.20	3	0.30	3	0.30
The system may use cost-efficient, smart technology.	6	3	0.18	1	0.06	1	0.06	4	0.24	4	0.24
The system may last between 5 and 10 years.	2	3	0.06	5	0.1	4	0.08	3	0.06	3	0.06
The system may be maintained every 6-12 months.	2	3	0.06	4	0.08	4	0.08	4	0.08	4	0.08
The system should provide an indication to the user their proximity to objects on the sides and back.	10	3	0.30	4	0.40	4	0.40	4	0.40	4	0.40
The system may be up to 10kg in weight.	2	3	0.06	4	0.04	3	0.06	4	0.08	4	0.08
The system may give at least 170 degrees of visibility.	8	3	0.24	1	0.08	1	0.08	5	0.4	5	0.4
The system should cost a maximum of \$100.	5	3	0.15	5	0.25	5	0.25	1	0.05	1	0.05
The screen may be a resolution of 320x240 - 1280x720.	6	3	0.18	0	0.00	0	0.00	4	0.24	4	0.24
The screen may be a size of 14cmx18cm - 35cmx25cm.	4	3	0.12	0	0	0	0	0	0	0	0
The system should have a battery life of 8-8hrs.	5	3	0.15	5	0.25	5	0.25	3	0.15	3	0.15
The system must be built to attach to the existing chair and will not interfere with the frame.	7	3	0.21	3	0.21	2	0.14	4	0.28	4	0.28
The display may be located such that it does not get in the way of wheelchair operation.	6	3	0.18	3	0.18	1	0.06	5	0.30	5	0.30
The display must be designed such that it does not get in the way of getting in and out of the wheelchair.	6	3	0.18	4	0.24	4	0.24	5	0.3	5	0.3
The system should be user friendly.	6	3	0.18	2	0.12	2	0.12	3	0.18	3	0.18
Total Score			3.00		2.51		2.32		3.76		3.76
Rank			2		4		3		1		1
Continue?			N		N		N		N		N

Table 6. Raveen's solutions.

		Concepts									
		Segment		1		2		3		4	
Selection Criteria	Weight (%)	Rating Notes	Wtd	Rating Notes	Wtd	Rating Notes	Wtd	Rating Notes	Rtd	Rating Notes	Rtd
The system may help patients become more independently mobile both in and out of the hospital.	5	3	0.15	1	0.05	3	0.15	4	0.2	3	0.15
The system should provide users with an increase in their spatial awareness.	10	3	0.3	1	0.1	3	0.3	4	0.4	3	0.3
The system should provide warning of obstacles to the user.	10	3	0.3	2	0.2	1	0.10	4	0.4	3	0.3
The system may use cost-efficient, smart technology.	6	3	0.18	3	0.18	2	0.12	3	0.18	2	0.12
The system may last between 5 and 10 years.	2	3	0.06	4	0.04	2	0.04	3	0.06	2	0.04
The system may be maintained every 6-12 months.	2	3	0.06	3	0.06	4	0.06	3	0.06	3	0.06
The system should provide an indication to the user their proximity to objects on the sides and back.	10	3	0.3	1	0.1	4	0.4	4	0.4	4	0.4
The system may be up to 10kg in weight.	2	3	0.06	5	0.1	3	0.06	3	0.06	4	0.08
The system may give at least 170 degrees of visibility.	8	3	0.24	1	0.08	3	0.32	4	0.32	1	0.08
The system should cost a maximum of \$100.	5	3	0.15	5	0.25	3	0.15	3	0.15	3	0.15
The screen may be a resolution of 320x240 - 1280x720.	6	3	0.18	1	0.06	3	0.18	4	0.24	1	0.06
The screen may be a size of 14cmx18cm - 35cmx25cm.	4	3	0.12	1	0.04	3	0.12	4	0.16	1	0.04
The system should have a battery life of 8-8hrs.	5	3	0.15	1	0.05	3	0.15	4	0.2	1	0.05
The system must be built to attach to the existing chair and will not interfere with the frame.	7	3	0.21	2	0.14	3	0.21	4	0.28	3	0.21
The display may be located such that it does not get in the way of wheelchair operation.	6	3	0.18	2	0.12	3	0.18	4	0.24	1	0.06
The display may be designed such that it does not get in the way of getting in and out of the wheelchair.	6	3	0.18	2	0.12	3	0.18	4	0.24	1	0.06
The system should be user friendly.	6	3	0.18	1	0.06	3	0.18	4	0.24	3	0.18

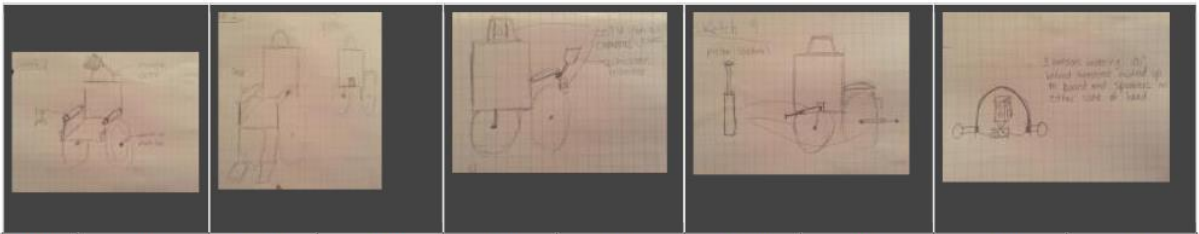
Total Score	3	1.75	2.9	3.59	2.34
Rank	2	4		1	3
Continue?	yes	no	no	yes	no

Table 7. Quang-Vinh's solutions.

		Concepts											
Segment		Mirrors				Cushion			Sensor + display/brakes			Camera + display	
													
Selection Criteria	Weight (%)	Rating	Notes	Wtd	Rating	Notes	Wtd	Rating	Notes	Wtd	Rating	Notes	Rtd
The system may help patients become more independently mobile both in and out of the hospital.	5	3	Helps by increasing spatial awareness	0.15	2	User will still not be able to see around them	0.10	4.5	Helps avoid collisions	0.225	4.5	Gives user much more range of view	0.225
The system should provide users with an increase in their spatial awareness.	10	3	Gives better range of view	0.3	1	Does not increase spatial awareness	0.10	1	Does not increase spatial awareness	0.10	5	Gives 360 degree view	0.50
The system should provide warning of obstacles to the user.	10	3	Only warning is from mirrors	0.30	3.5	Slight warning when the cushion touches obstacle	0.35	5	Gives warning + automatic brake	0.50	3	Only warning is from display	0.30

The system may use cost-efficient, smart technology.	6	3	Does not use smart tech	0.18	3	Does not use smart tech	0.18	5	Uses proximity sensors and display	0.30	5	Uses camera + display	0.30
The system may last between 5 and 10 years.	2	3	Lasts as long as mirrors are not broken	0.06	4	Cushions will last a long time	0.08	2	May break/need replacing within 10 years	0.04	2	May break/need replacing within 10 years	0.04
The system may be maintained every 6-12 months.	2	3	Rarely needs maintenance	0.06	3	Rarely needs maintenance	0.06	3	Needs yearly maintenance	0.06	3	Needs yearly maintenance	0.06
The system should provide an indication to the user their proximity to objects on the sides and back.	10	3	Proximity can be seen with mirrors	0.3	1	Does not provide indication of proximity	0.10	5	Uses proximity sensors to give indication	0.50	3	Proximity can be seen with camera	0.3
The system may be up to 10kg in weight.	2	3	Weights much less than 10 kg	0.06	3	Weights much less than 10 kg	0.06	3	Weights much less than 10kg	0.06	3	Weights much less than 10 kg	0.06
The system may give at least 170 degrees of visibility.	8	3	Can give over 170 degree view	0.24	1	Does not give any view	0.08	1	Does not give any view	0.08	5	Gives full 360 degree view	0.40
The system should cost a maximum of \$100.	5	3	Costs around \$70	0.15	3	Costs around \$70	0.15	3	Will cost around \$70	0.15	2	Will cost more than \$70	0.10
The screen may be a resolution of 320x240 - 1280x720.	6	3	No screen	0.18	3	No screen	0.18	5	Screen is within resolution specs	0.30	5	Screen resolution is within specs	0.30
The screen may be a size of 14cmx18cm - 35cmx25cm.	4	3	No Screen	0.12	3	No screen	0.12	5	Size is within specs	0.20	5	Size is within specs	0.20
The system should have a battery life of 6-8hrs.	5	3	No battery required	0.15	3	No battery required	0.15	3	Battery life around 6 hours	0.15	3	Battery life around 6 hours	0.15
The system must be built to attach to the existing chair and will not interfere with the frame.	7	3	Can be attached without interfering	0.21	3	Can be attached without interfering	0.21	3	Can be attached without interfering	0.21	3	Can be attached without interfering	0.21
The display may be located such that it does not get in the way of wheelchair operation.	6	3	Mirrors can be positioned to not interfere	0.18	3	Cushions will not interfere	0.18	3	Can be positioned or moved to not interfere	0.18	3	Can be positioned or moved to not interfere	0.18
The display may be designed such that it does not get in the way of getting in and out of the wheelchair.	6	3	Mirrors can be placed to be out of way	0.18	3	Cushions won't be in the way of user	0.18	3	Can be moved to be out of the way	0.18	3	Can be moved out of way	0.18
The system should be user friendly.	6	3	Similar to a car so it is user friendly	0.18	5	Requires no input from user	0.30	4	Only one display to look at	0.24	3	Contains only display with buttons to move camera	0.24
Total Score	3				2.58			3.475			3.745		
Rank	3				4			2			1		
Continue?	No				No			Maybe			Maybe		


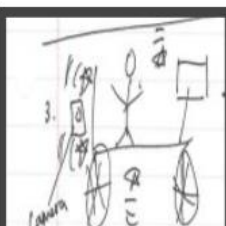
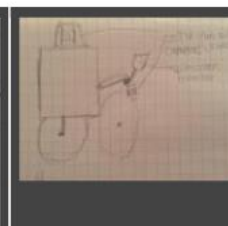

Table 8. Ivan's solutions.

Concepts											
Segment											
Selection Criteria	Weight (%)	Rating	Wtd	Rating	Wtd	Rating	Wtd	Rating	Wtd	Rating	Wtd
The system may help patients become more independently mobile both in and out of the hospital.	5	3	0.15	2	0.1	4	0.40	2	0.1	4	0.2
The system should provide users with an increase in their spatial awareness.	10	3	0.3	2	0.2	4	0.40	1	0.1	4	0.4
The system should provide warning of obstacles to the user.	10	3	0.3	4	0.4	1	0.10	4	0.4	4	0.4
The system may use cost-efficient, smart technology.	6	3	0.18	4	0.24	3	0.18	5	0.3	4	0.24
The system may last between 5 and 10 years.	2	3	0.06	5	0.1	3	0.06	5	0.1	4	0.08
The system may be maintained every 6-12 months.	2	3	0.06	4	0.08	2	0.04	5	0.1	4	0.08
The system should provide an indication to the user their proximity to objects on the sides and back.	10	3	0.3	4	0.4	4	0.40	3	0.3	4	0.4
The system may be up to 10kg in weight.	2	3	0.06	5	0.1	1	0.02	4	0.08	4	0.08
The system may give at least 170 degrees of visibility.	8	3	0.24	0	0	4	0.32	0	0	0	0
The system should cost a maximum of \$100.	5	3	0.15	4	0.2	1	0.05	5	0.25	4	0.2
The screen may be a resolution of 320x240 - 1280x720.	6	3	0.18	0	0	3	0.18	0	0	0	0
The screen may be a size of 14cmx18cm - 35cmx25cm.	4	3	0.12	0	0	3	0.12	0	0	0	0

The system should have a battery life of 8-8hrs.	5	3	0.15	5	0.25	3	0.15	5	0.25	4	0.2
The system must be built to attach to the existing chair and will not interfere with the frame.	7	3	0.21	5	0.35	2	0.14	5	0.35	4	0.28
The display may be located such that it does not get in the way of wheelchair operation.	6	3	0.18	0	0	3	0.18	0	0	0	0
The display may be designed such that it does not get in the way of getting in and out of the wheelchair.	6	3	0.18	0	0	3	0.18	0	0	0	0
The system should be user friendly.	6	3	0.18	5	0.3	3	0.18	5	0.3	4	0.24
Total Score	3		2.72			3.10		2.63		2.72	
Rank	2		3			1		4		3	
Continue?	N		N			Y		N		N	

From these individual concepts, the best option was selected and the resulting four solutions were compared using a design matrix.

Table 9. Individual solution comparison.

	Segment								
		Nathalia's (#8)	Raveen's (#4)	Ivan's (#3)	Quang-Vinh's (#4)				
Selection Criteria	Weight (%)	Rating	Wtd	Rating	Wtd	Rating	Wtd	Rating	Rtd
The system may help patients become more independently mobile both in and out of the hospital.	5	3	0.15	3	0.15	4	0.40	3	0.15
The system should provide users with an increase in their spatial awareness.	10	3	0.30	3	0.30	4	0.40	3	0.30
The system should provide warning of obstacles to the user.	10	3	0.30	3	0.30	1	0.10	3	0.30
The system may use cost-efficient, smart technology.	6	3	0.18	3	0.18	3	0.18	2	0.12
The system may last between 5 and 10 years.	2	3	0.06	3	0.06	3	0.06	2	0.04
The system may be maintained every 6-12 months.	2	3	0.06	3	0.06	2	0.04	3	0.06
The system should provide an indication to the user their proximity to objects on the sides and back.	10	3	0.30	4	0.40	4	0.40	2	0.20
The system may be up to 10kg in weight.	2	3	0.06	3	0.06	1	0.02	3	0.06
The system may give at least 170 degrees of visibility.	8	3	0.24	3	0.24	4	0.32	5	0.4
The system should cost a maximum of \$100.	5	3	0.15	3	0.15	1	0.05	2	0.10
The screen may be a resolution of 320x240 - 1280x720.	6	3	0.18	3	0.18	3	0.18	3	0.18
The screen may be a size of 14cmx18cm - 35cmx25cm.	4	3	0.12	3	0.12	3	0.12	3	0.12
The system should have a battery life of 8-8hrs.	5	3	0.15	3	0.15	3	0.15	2	0.1
The system must be built to attach to the existing chair and will not interfere with the frame.	7	3	0.21	3	0.21	2	0.14	3	0.21
The display may be located such that it does not get in the way of wheelchair operation.	6	3	0.18	3	0.18	3	0.18	3	0.18
The display must be designed such that it does not get in the way of getting in and out of the wheelchair.	6	3	0.18	3	0.18	3	0.18	3	0.18
The system may give at least 170 degrees of visibility.	8	3	0.24	3	0.24			5	0.4
The system should cost a maximum of \$100.	5	3	0.15	3	0.15			2	0.10
The screen may be a resolution of 320x240 - 1280x720.	6	3	0.18	3	0.18			3	0.18
The screen may be a size of 14cmx18cm - 35cmx25cm.	4	3	0.12	3	0.12			3	0.12
The system should have a battery life of 8-8hrs.	5	3	0.15	3	0.15			2	0.1
The system must be built to attach to the existing chair and will not interfere with the frame.	7	3	0.21	3	0.21			3	0.21
The display may be located such that it does not get in the way of wheelchair operation.	6	3	0.18	3	0.18			3	0.18
The display must be designed such that it does not get in the way of getting in and out of the wheelchair.	6	3	0.18	3	0.18			3	0.18
The system should be user friendly.	6	3	0.18	3	0.18			3	0.18
Total Score			3.00		3.10		0.00		2.88
Rank									
Continue?			Partly		Partly		Partly		Partly

From this a final design was created:

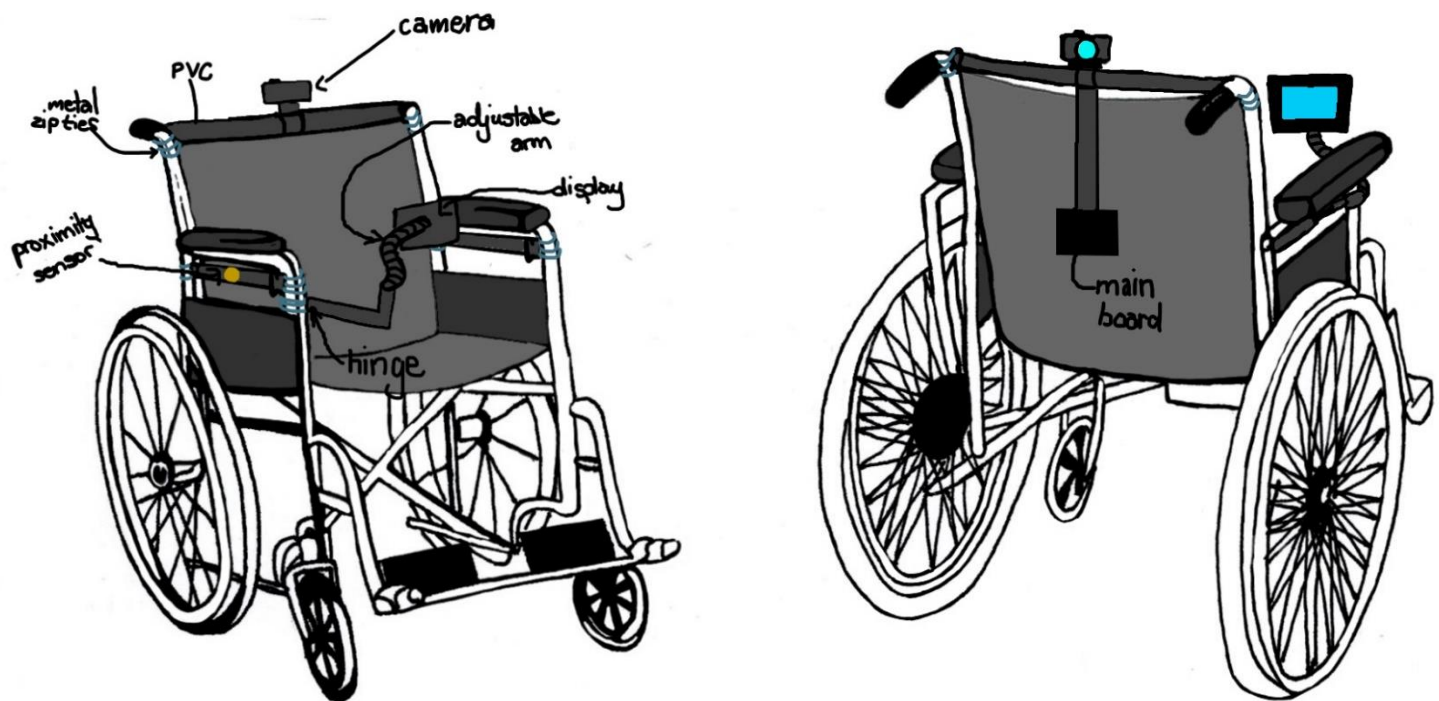


Figure 5. Final design sketch of both frontal and rear views.

The final design uses an incorporation of the best individual designs which had different strengths against different design criteria. The final product therefore satisfies all of the design criteria:

- The system may help patients become more independently mobile both in and out of the hospital.
 - The designed system will allow patients to steer clear of obstacles and will therefore be able to operate their wheelchair with less assistance.
- The system should provide users with an increase in their spatial awareness.
 - The system provides a view of the area behind the wheelchair as well as indicating the presence of obstacles. It also provides an indication of obstacles to the sides.
- The system should provide warning of obstacles to the user.
 - The system uses proximity sensors at the back and the sides to indicate approaching obstacles to the user.
- The system may use cost-efficient, smart technology.
 - The system will indicate the proximity of approaching obstacles to the user and will show the user the view of their rear. This system can be built using cost-efficient materials to meet the budget to make up for the more expensive components.

- The system may last between 5 and 10 years.
 - Due to the use of strong materials and limited moving parts, the system will have a longer user life.
- The system may be maintained every 6-12 months.
 - The system is simple enough to require minimum maintenance.
- The system should provide an indication to the user their proximity to objects on the sides and back.
 - The system uses proximity sensors at the back and the sides to indicate approaching obstacles to the user.
- The system may be up to 10kg in weight.
 - The system will use a light-weight strong material and small components to cut down on weight.
- The system may give at least 170 degrees of visibility.
 - The camera will provide this degree of visibility to the rear.
- The system should cost a maximum of \$100.
 - This system can be built using cost-efficient materials to meet the budget to make up for the more expensive components.
- The screen may be a resolution of 320x240 - 1280x720.
 - The display will meet this design criteria.
- The screen may be a size of 14cmx18cm - 35cmx25cm.
 - The display can be moved out of the way so it can be a larger size.
- The system should have a battery life of 8-8hrs.
 - Less automatically moving parts means that the battery life will be longer.
- The system must be built to attach to the existing chair and will not interfere with the frame.
 - The system will be built to be removable. This will also help with maintenance.
- The display may be located such that it does not get in the way of wheelchair operation.
 - The display is on an adjustable arm attached to an arm that puts the display far enough away from the user that they will not bump into it while operating the wheelchair.
- The display maybe designed in such a way that it does not get in the way of the user getting in and out of the wheelchair.
 - The display rests on an arm that is hinged, therefore the user can push it out of the way.
- The system should be user friendly.
 - The design is simple enough for many users to grasp and is adjustable to the user.

Core Functionality

The group concept involves combining the ideas of the proximity sensor along with the camera to give both increased spatial awareness along with the added warning of hitting an obstacle. The proximity sensors will be attached to the sides of the arm rests and will face the sides of the wheelchair. They will monitor the distance between the wheels and the wall and when the wheels are too close, they will output an increasing warning. For the camera, it will be mounted on a PVC pipe that will be connected between and below the two handles of the wheelchair. The

camera will face the back of the wheelchair which will give around 170 degrees of view. As such, with both the proximity sensors and camera, the system will cover both the sides and the back. To display the information taken in by the sensors and camera, a display will be attached near the armrest. It will be mounted to an arm which will allow the user to move it as they please. The screen will display the information from the camera at the back. It can also display information taken in by the sensors. When an obstacle is too near then the screen can display an indication about the near collision.

Relation to Target Specifications, Benefits and Drawbacks

This idea was formulated based on the design criteria, which was synthesized from the problem statement, target specifications and metrics of the project. Furthermore, these were created from analysing the needs provided by interviewing the hospital technician, Mr. N'Diaye's, whose experience allows him to empathise with the future user. When formulating the final concept, the individual concepts were considered and assessed based on the design criteria using a design matrix. Therefore where one of the individual ideas was lacking against design criteria, the other ideas compensated for it. Furthermore, in order to meet design criteria some compensations were made. For example, the proximity sensors don't provide any increased spatial awareness, however the camera does. From examining the decision matrixes and looking at the max values of both ideas, we can see that every metric is met within the target specifications. (See section "Justification of Design")

Benefits of the Final Design:

- User friendly (little input from user required)
- Over 170 degree spatial awareness of back
- Proximity sensors give early detection of collision
- Lightweight
- Will not compromise the frame
- Yearly maintenance

Drawbacks of the Final Design:

- Uses some expensive components.
- Uses some technology which has a higher chance of breaking and failure.

In this importance stage of concept design, the target specifications, problem statement and metrics were used to create design criteria to base concept generation on. The next stage after this concept generation was to plan the more specifics of the design, such as the finances, and test the feasibility of our design.

6.0 Project Plan

Once the design had been created, a plan was created to ensure that all required tasks were completed on time and all group members were aware of their responsibilities. A timeline for the project was also determined where tasks were set to start October 10th and the project was set to be completed by November 22nd. Although the Design Day for the project was not until the 29th of November, it was decided that it would be beneficial to plan to end early in case of last minute changes to the design due to client feedback.

The project plan was organised according to a traditional Plan and Execute method. This approach was selected as the project was determined to long-termed; thus, the tasks needed to be organised along a time frame of a few weeks. This project plan consisted of three components: a list of tasks, a list of milestones and a Gantt Diagram.

5.1 List of tasks. Based on the project design, tasks were created to ensure even delegation of tasks amongst the group members and to ensure completion. The task lists were divided by generality and prototype where sub-list I was assigned to Prototype I, sub-list II was assigned to Prototype II and sub-list III was assigned to Prototype Testing.

Table 10. General List of Tasks

Project Component	Task	Task Dependencie s	Duration	Member Responsible
D: Project Plan and Feasibility Study	Report Completion	Project C	1 week	All
E: Design Prototype I	See sub-list 1	Project D	1 week	All See sub-list I
F: Business Model	Report Completion	Project B-D	1 week	All
G: Customer Validation	Report Completion	Prototype I	2 days	All
H: Economic Report and Video Pitch	Report and Video Completion	Project B-G	1 week	All
I: Prototype II and customer feedback		Project B-H	2 weeks	All
	See Sub-list "Testing"			All See sub-list III
	See sub-list "Building"			All See sub-list II
J: Project Presentations	Presentation Completion	Project B-I	4 days	All

K: Final Report	Report Completion	Project B-J	3 days	All
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Table 10 displays a general list of tasks including project deliverables, associated tasks, task dependencies and duration. Furthermore, the table displays the assignment of tasks to group members. The purpose of this table was to create a basis for a time-table, to demonstrate dependencies and to assign references to task sub-lists.

Table 11. Sub-List I: Prototype I.

Task Grouping	Task	Dependencies	Duration	Member Responsible
E: Design Prototype I	1. Design Mini-Model of Wheelchair (3D Printing) on computer	Project A-D Ability to use software	4 days	Quang-Vinh
	2. Design Product Components (3D Printing) on computer	Project A-D Ability to use software	4 days	Raveen
	3. Design Bar Attachment Model (3D Printing) on computer	Project A-D Ability to use software	4 days	Nathalia
	4. 3D Print Components (Makerlab)	E1-E3 Makerlab operation hours	½ day	Nathalia
	5. Assemble Models	E4	½ day	Nathalia

Table 11 displays a list of tasks required to complete the first prototype which included 3 models: a 3D printed wheelchair model and a Bar Attachment. However, during the prototyping process, another two prototypes were created including a Mock Display and a Mock Wheel. For more information on prototype I please refer to section 7.0 Prototype I. The purpose of this task list was to demonstrate the required tasks associated with building prototype I and to assign these responsibilities to group members.

Table 12. Sub-List II: Prototype II

Task Grouping and Lead	Task	Dependencies	Duration	Member Responsible
Central Arduino System (CAS) Quang-Vinh	1. Buy components	BOM	5 days	Nathalia
	2. Assembly of Arduino board components	1.	2 hours	Quang-Vinh
	3. Programming Arduino board to sensors, speakers	1, 2	3 days	Quang-Vinh
	4. Attachment of power supply	1,2	1 day	Quang-Vinh
	5. Attachment and construction of wiring to all of the system	1 -4 Sensors in position	2 days	Ivan
	6. Attachment of system to wheelchair	1-5	1 day	Nathalia
	7. System Testing	1-5	½ day	Ivan, Quang-Vinh
	8. Modifications	7	½ day	Quang-Vinh
Lateral Proximal Proximity Sensor System (LPPSS) Ivan	1. Buy components	BOM	5 days	Nathalia
	2. Attachment of sensors to CAS (wiring)	CAS (1-4)	½ day	Ivan
	3. Build bar attachment to chair (x2)		1 day	Ivan
	4. Build attachment of bar to chair (x2)	3	½ day	Nathalia
	5. Attach sensors to bar (x2)	3,4	½ day	Nathalia
	6. System Testing	2-5	2 hours	Nathalia
	7. Modifications	1-6	1 hour	Ivan, Quang-Vinh

Medial Distal Sensor System (MDSS) Ivan	1. Buy components	BOM	5 days	Nathalia
	2. Build sensor attachment	1	½ day	Ivan
	3. Attach sensors to attachment	1,2	1 hour	Raveen
	4. Wire sensors to system	1-3, CAS (1-4)	½ day	Ivan
	5. Attach to wheelchair	1-3	1 hour	Ivan
	6. System Test	1-5, CAS (1-4), LPPSS (1-5), PVCS (1-5)	2 hours	Ivan, Quang-Vinh
	7. Modifications	1-6	½ day	Ivan
Posterior Visual Camera System (PVCS) Nathalia	1. Buy components	BOM	5 days	Nathalia
	2. Build bar attachment to chair	1	½ day	Nathalia
	3. Build attachment of bar to chair	2	½ day	Nathalia
	4. Attach camera to bar	2,3	1 hour	Nathalia
	5. Wire camera to CAS	CAS (1-4)	1 day	Ivan
	6. Assembly of bars to wheelchair	1-5	1 hour	Nathalia
	7. System test	1-6	3 hours	Ivan, Quang-Vinh
	8. Modifications	7	½ day	Nathalia
Main Medial Visual Display (MMVD) Raveen	1. Buy components	BOM	5 days	Nathalia
	2. Build main arm	1	½ day	Nathalia
	3. Attach gooseneck to main arm	1,2	2 hours	Raveen
	4. Construct Hinge Attachment	1	½ day	Raveen
	5. Attach arm to wheelchair	1-4	1 hour	Raveen, Nathalia

	6. Attach the display	1-4	1 hour	Raveen, Nathalia
	7. Connect the display to the CAS	CAS (1-4)	2 hours	Raveen, Ivan
	8. System testing	1-7 CAS (1-4), LPPSS (1-5)	3 hours	Ivan, Quang-Vinh
	9. Modifications	1-8	½ day	Raveen
Main Speaker Alert System (MSAS) Nathalia	1. Buy components	BOM	5 days	Nathalia
	2. Attach speakers to bar of PVCS	PVCS 1-3	2 hours	Nathalia
	3. Wire speakers to CAS	CAS(1-4), LPPSS (1-5)	2 hours	Ivan
	4. System Testing	1-3, CAS(1-4), LPPSS (1-5)	3 hours	Ivan, Quang-Vinh
	5. Modifications	1-4	½ day	Raveen

Table 12 displays a list of tasks required to complete the second prototype which divided the tasks based on the model's subsystems. For more information on Prototype II please refer to section 8.0 Prototype II. The purpose of this task list was to demonstrate the required tasks associated with building prototype II and to assign these responsibilities to group members.

Table 13. Sub-List III Testing

Task Grouping	Task	Dependencies	Duration	Member Responsible
E: Design Prototype I G: Customer Validation	1. Test physical bar attachment to Wheelchair	Prototype I	1 hour	Quang-Vinh
	2. Test conceptual, physical model [to client]	Prototype I	3 hours	Ivan
I: Prototype II	1. Arduino system functional test (sensors, display, etc.)	Functional Arduino system and power system	4 hours	Ivan, Quang-Vinh
	2. Test functional power system	Functional Arduino system and power system	1 hour	Ivan, Quang-Vinh

	3. Test functional proximity sensor sensibility to specs	Functional Arduino system and power system	1 hour	Ivan, Quang-Vinh
	4. Test functional sound system to proximity sensor system	Functional Arduino system and power system	2 hours	All
	5. Test strength of functional display arm	Functional, attached arm	1 hour	Raveen
	6. Test physical strength of attachment of foot sensors	Physical attachment and wiring of foot sensors	1 hour	Ivan, Quang-Vinh

Table 13 displays a list of tasks required to test both prototypes. The tasks were therefore divided by prototype and assigned to corresponding group members. The purpose of this task list was to determine the necessary tests and to assign the responsibilities to group members.

6.2 Milestones.

Table 14. Milestones

Task	Milestone Date	Main Member Responsible
Prototype I	October 22 nd 2017	Nathalia
Prototype I Testing	October 22 nd 2017	Quang-Vinh
Prototype I Customer Feedback	October 27 th 2017	Ivan
E: Design Prototype I	October 29 th 2017	Nathalia
Buy components (BOM)	October 30 th 2017	Nathalia
Functional programmed Arduino board (CAS)	November 3 rd 2017	Quang-Vinh
Functional sensors (CAS, LPPSS, MDSS, PVCS)	November 4 th 2017	Quang-Vinh, Ivan
Functional CAS system to speakers and display	November 5 th 2017	Group
F: Business Model	November 5 th 2017	Group
Bar Construction (LPPSS, MMVD)	November 10 th 2017	Nathalia
Attachment of System to bars	November 11 th 2017	Group
Sensor Attachment MDSS	November 11 th 2017	Ivan

Display Arm Completed (MMVD)	November 11 th 2017	Raveen
System Wired and Constructed	November 12 th 2017	Group
Prototype II Testing	November 14 th 2017	Ivan, Quang-Vinh
Functional first Prototype II	November 15 th 2017	Group
G: Customer Validation	November 15 th 2017	Group
H: Economic Report and Video Pitch	November 19 th 2017	Group
Completed Prototype II	November 22 nd 2017	
I: Prototype II and Customer Feedback	November 26 th	Group
J: Project Presentations	November 26 th	Group
K: Final Report	December 3 rd 2017	Group

Based on the project timeline, which spanned from October 10th to November 22nd, the task lists and the assigned delivery dates for various deliverables, a list of Milestones was created. The purpose of this list was to ensure dates for milestones were established and acknowledged by all members.

6.3 Gantt diagram. A Gantt diagram was created to incorporate milestones and tasks into a timeline that would ensure the completion of the project on-time. In order to create this document, tasks were linked to each other by dependencies and their completion duration was approximated. The tasks were colour-coded by which component of the project they fell under.

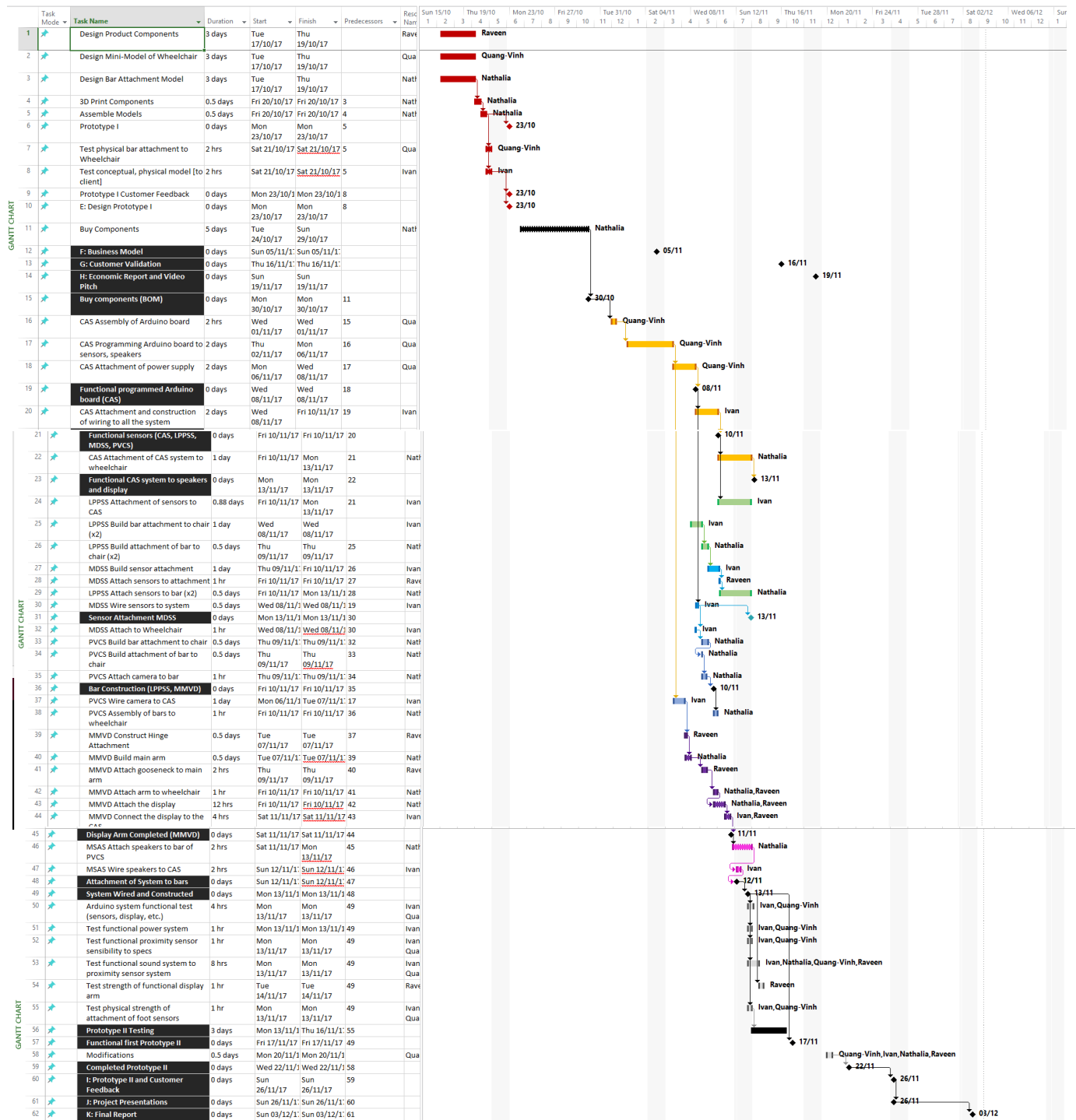


Figure 6. Gantt Diagram
This figure displays the project Gantt Diagram.

6.4 Project uncertainties. During the project's planning process, some uncertainties and risks were determined in relation to the iterated design. The first uncertainty was involving the reversing camera and display system. There was concern regarding the image quality produced on the screen in both its clarity and field of view. In order for the system to be effective, the user must be able to see a larger field of view of the environment to their rear and the image needs to be clear in its depiction of this. Another uncertainty was to do with the placement and arrangement of the sensors, as it was unknown whether or not the sensors could be programmed to be sensitive within a certain range. Furthermore, a risk associated with the design is the durability of the system's components. Given that the product is catered towards the elderly, the components needed to be able to withstand damage. The last risk associated with the project was the assumption that our group members would be capable of coding and wiring the Arduino-sensor system to work in synchrony. As the sensors was a critical part of the design, this was the largest risk of the project.

6.5 Bill of materials. From the final design of the product, a bill of materials was created to keep track of all the required items and ensure that the cost of every component was accounted for. As the product was restricted to a \$100.00 budget, the cost of all parts was attempted to be minimized as much as possible. To reduce the costs of electronic parts, as many of these items were attempted to be bought locally if possible in order to avoid shipping costs online. As well, to reduce the costs of several mounts and structural components, 3D printing was used to produce these parts at no costs.

Table 15. Bill of materials.

Category	Item Number	Part Name	Description	Quantity	Unit Cost	Extended Cost
1.0	1.1	½ inch x 10 feet PVC Pipe	Provides enough strength and is thick enough to run wires through	1	\$17.00	\$17.00
	1.2	1 inch x 10 feet PVC Pipe	Provides enough strength and is thick enough to run wires through	1	\$11.00	\$11.00
	1.2	PVC Elbow	Provides enough strength for joint	1	\$2.81	\$2.81
	1.3	¼ inch screws	Secure Pipe	1	\$0.00	\$0.00
	1.4	LOOMEX connectors	Secure Pipe	3	\$3.15	\$9.45
	1.5	Velcro Zip Ties	Secure Pipe	1	\$10.08	\$10.08
	1.6	ABS Glue	Connect 3D print to PVC	<1	\$0.00	\$0.00
2.0	2.1	Arduino-Uno	Provides minimum amount of connections	1	\$6.40	\$6.40

			for mounting of 5 sensors			
	2.2	Speakers	Outputs sensor information to user	1	\$3.41	\$0.00
	2.3	Battery	Powers Arduino board and sensors	1	\$36.99	\$36.99
	2.4	Arduino Mounting Board	Holds Arduino board to wheelchair	1	\$0.00	\$0.00
	2.5	Attachments	Attaches Arduino Mounting board to PVC pipe	1	\$0.00	\$0.00
3.0	3.1	Rear View Camera	Capable of providing a large range of view for the rear (170 degrees)	1	\$29.99	\$29.99
	3.2	Camera mount	Mount the camera to the wheelchair	1	\$0.00	\$0.00
	3.3	Arduino Proximity Sensor	Can detect distance from a near object	4	\$2.00	\$8.00
	3.4	Sensor Mount	Mount sensors to the side of the wheelchair	4	\$0.00	\$0.00
4.0	4.1	Display	Compact screen capable of displaying a live video of the rear view of the wheelchair	1	\$23.99	\$23.99
	4.2	Display Mount	Responsible for attaching the display to the gooseneck	1	\$0.00	\$0.00
	4.3	Gooseneck	Attaches to display, adjustable	1	\$29.85	\$29.85
	4.4	Hinge	Responsible for attaching gooseneck to the PVC pipe.	1	\$0.00	\$0.00
	4.5	Mount	Attaching PVC pipe to the wheelchair	1	\$0.00	\$0.00
Total Cost						\$185.56

Table 15 displays the bill of materials for the project.

5.6 Feasibility study. In order to determine if the scope of the project was feasible, based on the final design, a feasibility study was performed that used the TELOS factors:

Technical

Our team did not have the expertise and technical resources in order to create our product and are willing to fill in any gaps in knowledge we may come across during the project. Firstly, many members of the team have done building projects before. As such, we had a lot of experience in creating mounts and attaching the components to the wheelchair frame. Next, for the coding component for the Arduino, some members had taken several computing courses and had experience coding in C/C++ before which the Arduino uses. Thus, coding the logic won't be too difficult. Also, the sensors that used will be the same as used in the lab and so we were able to reuse the libraries and code used. For the speaker and any other component, there was a vast list of libraries and documentation from the Arduino website which we can use in order to easily implement those parts.

Economic

The project, although stretching the original budget of \$100, was able to remain within range of the BOM. One of the biggest factors to meet our budget was to use as much of the resources provided by the university as possible. For example, we wanted to 3D print as many things as we can and make use of all the free materials provided. The most expensive things in which we needed to strategically spend money in the budget is the display, camera, sensors, and the Arduino board. The only problem is that the quality of these products, which is required for our specific design, is directly correlated with the price. In order to stay on budget, we had to find the most reasonable prices.

Legal

We believe our solution is a valid option for the problem put forth, however there may be legal issues when it comes to implementing our technology. For example, we would have to make sure that the system poses no risk to safety by compromising the frame or impacting the patient operating the wheelchair. Furthermore, we need to make sure that our complies with all safety standards. All these issues should be addressed when we provide Bocar with our prototype and we will ask him for any potential issues he might anticipate with our design with regards to legality.

Operational

Our team members all have other obligations that do not pertain to the project at hand. Therefore, the biggest organizational challenge was be the completion of tasks in a hierarchal fashion due to the nature of our design. Some team members were busier than others on certain weeks and it is important to spread the workload (within reason) proportionally to their availability to maximize our productivity so that if issues arise we can solve it as soon as possible. Also making appointments with Bocar was challenging because of his limited availability, having to meet with other teams and the availability of our team members. Meeting with Bocar is essential to the success of our product and is important we are capable of keeping in touch with him via indirectly or directly.

Scheduling

As expressed in the operational analysis, the members of the team had other commitments to other courses, groups, etc. Therefore, in order to ensure the project is completed and finished to ensure quality of design, there were a few things that had to be implemented. Firstly, individual schedules were shared to the member organising tasks. This member should take these schedule restrictions into consideration when planning tasks. Furthermore, any changes to schedules that impact task completion were shared with the group to ensure the task is still completed. Finally, all members were aware of the project schedule and should be committed to fulfil their dedications to the timetable.

7.0 Design Process Stage 4: Prototype I

The first prototype created was a low fidelity physical model used to give a physical representation of how the product would function, to be used to get better feedback from Bocar. This would also be used to test several components in the current design of the system.

7.1 Client feedback. Prior to creating the first prototype, the team had met with Bocar and Phil and presented to them a graphical illustration of the product in order to get feedback and possible improvements. The main comments that were received:

Bocar:

“It looks really good, you came up with some stuff I hadn’t thought of”: Bocar likes the general concept of the design’s main system.

- “I like the idea of the sensor – the early warning sensor – that’s really good. It’s really good to have them on the side but recently I’ve been noticing some patients are also having problem with the feet. Because somehow when you are driving or when you are turning the patients aren’t able to see the foot rest. Somehow there are a lot of obstacles there. Even people driving them can’t”: Bocar likes the idea of the proximity sensors on

the sides of the wheelchair and is suggesting to also put them on the foot rests to prevent patients also hitting their feet.

Phil:

- “... a lot of the time when staff is pushing someone if they get distracted and don’t pay attention to the front of the chair as much sometimes we’ll push a patient or turn a corner

and not turn it properly and the patient’s toes will hit up against the wall or a door or something” : Phil also thinks adding proximity sensors to the foot rests would be useful in

the early warning system.

- “Big toe is the optimised area”: For the added proximity sensor at the feet, the area of the

big toe is the best place to place it.

Overall, they were pleased with the idea however, had wanted that there be extra sensors on the foot rests as this was a common location where patients would collide with obstacles. This feedback was taken into account in the design of the first prototype.

7.2 Prototype I.I Wheelchair mini-model. The first component of the prototype was a medium fidelity small-scale 3D printed model of the wheelchair along with the product attached. The main purpose is to be used as a conceptual reference for Bocar in the next client meeting and to validate design ideas. Due to feedback from the client meeting, additional proximity sensors were added below the foot rests.

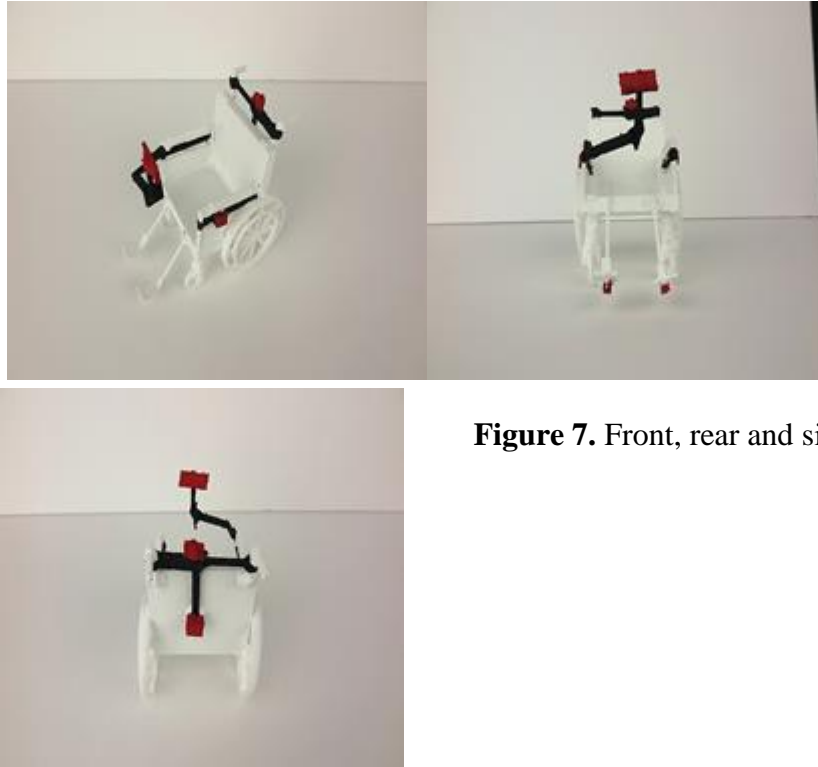


Figure 7. Front, rear and side view of prototype I.II

7.3 Prototype I.II bar attachment model. The second component of the prototype was a low fidelity to scale 3D printed physical model of the attachment of pvc pipes to the wheelchair frame. The objective of this attachment is to not compromise the frame in any way while also providing a strong attachment onto the wheelchair to be able to support the weight of the components. The main purpose of this prototype is to be able to test the structural attachment as was created in the design process.



Figure 8. Frontal view of prototype I.II

To test the prototype for structural attachment strength, the prototype was first attached to a pole representing a pole on the wheelchair frame. A downward force was then applied to the prototype and observations were recorded. It was seen that the attachment was able to support the mass of the electrical components that it was to hold. As well, with stronger materials the attachment will be able to support more weight than was used in testing. Thus the attachment system is functional.



Figure 9. Downward load applied in testing prototype I.II.

7.4 Prototype I.III mock display. The mock display prototype is a to scale low fidelity physical model of screen along with the bar that is used to attach it to the wheelchair. This prototype was made using Styrofoam and construction paper. The purpose is to test the ergonomics of the display and arm design and whether it is a suitable design for client use.



Figure 10. Frontal view of Prototype I.III

To test the design, we had 16 test subjects sit in a chair, placed the display in front of them and had them pretend to use it. From the test subject feedback, 16/16 (100%) had preferred that the display arm be adjustable to match their specific height and also to be adjustable and be easily moved out of the way. Thus, the current design of the display arm had to be improved in further prototypes.

7.5 Prototype I.IV mock wheel. This prototype a small scale physical model of a wheel made from construction paper. The purpose of this prototype is to test whether the minimum distance the proximity sensors currently detect are reasonable.



Figure 111. Frontal view of Prototype I.IV

To test this design, several distances were marked on a piece of paper from the wheel. Objects were then placed beside the wheel to mimic a user's hand and arm as well as objects they would be using in their wheelchair. The distances were then recorded from the wheel. It was found that an average of 5cm was reasonable for the minimum distance to set off the sensors as objects were within this range.

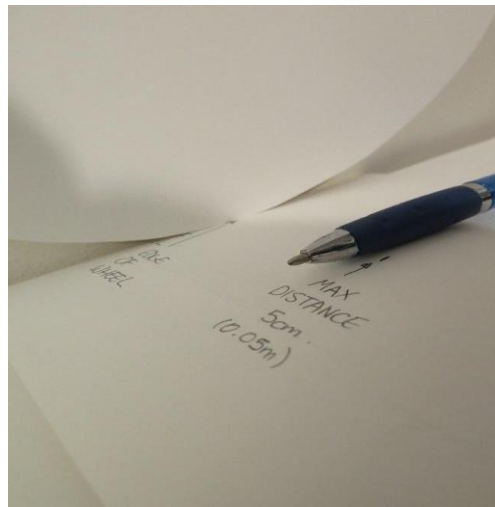


Figure 12. Prototype I.IV testing: measuring distances.

8.0 Design Process Stage 5: Prototype II and Testing

The second prototype for our design was a high-fidelity functional model.

8.1 Design goal. This project has sought to solve the problem of wheelchair user spatial awareness and their avoidance of obstacles. The main goal of Prototype II was to create a functioning model based off the design, similar to what the final product will look like, in order to get better feedback on the design from our client as well as to verify the project goal has been achieved. This prototype was of high fidelity and implemented all the functions that our final product will have. Thus, this gave Mr. N'Diaye a better understanding of what the final product would look like.

8.2 Prototype II function.

Proximity sensor system

The purpose of the proximity sensor system is to provide an adequate early warning detection of obstacles in the aims to reduce collision. The system consists of 4 proximity sensors, a speaker and an Arduino board. The 4 proximity sensors will be attached to both sides of the wheelchair and to the bottom of the foot rests. They will be used to get inputs on the surroundings and detect the distance from the wheelchair to an obstacle. The speaker will be used to display an alarm and provide a warning of a possible collision. The Arduino board will be used to handle the logic by using the inputs from the sensors in order to display an appropriate warning with the speakers. If an obstacle is detected within a certain distance 40 cm from any sensor, then the board will set the speakers to display a beeping alarm noise to notify the wheelchair user of a collision. The board has been coded to cause the frequency of the beeps to increase as the distance from the obstacle decreases. Also, due to the wheelchair user's arms potentially being in the way of the sensor during wheelchair use, the sensor has a minimum distance of 10 cm to set off an alert of an obstacle in the way.

Camera Display System

The main function of this part of the product is to display to the user a live video feed displaying the back portion of the wheelchair. It is especially important given that our clients may not be able to see the area behind them while in the wheelchair. This video feed is composed of a compact HD monitor attached to a adjustable goose neck, that is connected to the camera on the back of the wheelchair and is powered by the arduino board. One of the problems that we encountered with the Display was figuring out how we would mount it to the gooseneck attachment, as we had to make sure it would not fall off during movement. Lastly due to a delayed shipment we had to outsource a different display, which is more expensive and pushed us above our \$100 limit.

Display arm

The main function of the display arm is to support the Screen and allow easy entry and exit from the wheelchair. The main components of the system are the screen attachment, the gooseneck, and the hinge connection of the gooseneck to the PVC pipe frame. This system was especially important when considering that the monitor could not interfere with the daily use of the wheelchair user. Therefore, to make sure this problem was solved, we decided to attach the gooseneck on a hinge allowing the entirety of the camera display system to be moved easily out of the way of the user. In addition, we also decided to attach the monitor to a gooseneck, so that the screen could be moved depending on the user's preference. Ultimately with the addition of the gooseneck and the hinge, we have made the wheelchair system very ergonomic and practical for daily use.

8.3 Prototype II sub-systems. The second prototype consists of five subsystems. Each subsystem is named in accordance with their main task and their location to the user as described by anatomical position. While the original design had 6 subsystems, it was decided to merge the CAS and MSAS systems together. The following is a description of the subsystems:

Central Arduino System (CAS)

Function: This subsystem contains the Arduino unit, which controls the proximity sensors, and contains the battery which powers both electronic systems.

Structure: The CAS is connected by wiring to the proximity sensors, the camera system and the speakers. It is structurally connected via a PVC pipe to the PVCS which connects to the rear of the wheelchair.

Table 16. CAS list of materials.

Material	Quantity	Cost
Wire	16m	\$0.00
Speaker	1 unit	\$3.41
Arduino Uno	1 unit	\$6.40
12V Rechargeable Battery	1 unit	\$36.99
Proximity Sensors	4 units	\$8.00
PVC Pipe	0.35m	\$2.26
Plastic Box	1 unit	\$0.00
¼ Inch Screws	3 units	\$0.00
Perforated Metal Strapping	0.12m	\$0.00
Zip Ties	6 units	\$0.00
Total Cost		\$57.06

Table 16 displays the materials used to build the CAS system with their corresponding cost per one system.

Subsystem Assembly Process: This subsystem was assembled using the following steps:

1. Buy the necessary materials.
2. Code the Arduino Uno and create a schematic for wiring. See Appendix II for schematic.
3. Connect preliminary wires to the Arduino Uno to test function. Adjust code to ensure function.
4. Create a final wire that connects into the Arduino using pins and to the speakers and sensors using sockets. Also create a wire that connects the Arduino system to the speaker.
5. Cut the PVC pipe that connects the CAS to the PVCS. The connection uses perforated metal stripping and ¼ inch screws.
6. Attach the Arduino unit and battery to casing.
7. Attach the sensors to their mounts in the other subsystems.



Figure 12. CAS sub-system attached to PVCS

Lateral Proximal Proximity Sensor System (LPPSS)

Function: This subsystem attaches the side sensors to the wheelchair using a bar attachment system. The sensors are controlled and connect back to the CAS.

Structure: The sensors are mounted in 3D printed components which are attached to an adjustable PVC arm that uses two sizes of pipe. The arm is connected to the wheelchair using a 3D printed mount and Velcro zip ties.

Table 17. LPSS list of materials.

Material	Quantity	Cost
3D Printed PLA	6 units	\$0.00
1 inch PVC Pipe	0.40 m	\$2.30
0.5 inch PVC Pipe	0.40 m	\$1.33
¼ inch screws	8 units	\$0.00
Loomex Connector	2 units	\$9.02
Velcro Zipties	8 units	\$1.61
ABS Glue	>1 container	\$0.00
Total Cost		\$14.26

Table 17 displays the materials used to build the LPSS system with their corresponding cost per one system.

Subsystem Assembly Process: This subsystem was assembled using the following steps:

1. Buy the necessary materials.
2. Cut the PVC pipes down to size. See drawing in Appendix II.
3. Using the lathe machine, trim the size of the ½ inch PVC to fit in Loomex Connector.
4. Design a CAD model for the sensor mounts and bar attachments. Print the components and make any needed adjustments.
5. Using ABS glue, attach the 3D printed components and the Loomex Connector to the PVC piping.



Figure 13. LPSS sub-system.

Medial Distal Sensor System (MDSS)

Function: This subsystem attaches the foot-rest sensors to the wheelchair and the sensors are connected to the CAS.

Structure: The sensors are attached to 3D printed components which are attached to the wheelchair using Velcro zipties.

Table 18. MDSS list of materials.

Material	Quantity	Cost
3D Printed PLA	2 units	\$0.00
Velcro Zipties	4 units	\$0.80
	Total Cost	\$0.80

Table 18 displays the materials used to build the MDSS system with their corresponding cost per one system.

Subsystem Assembly Process: This subsystem was assembled using the following steps:

1. Buy the necessary materials.
2. Design a CAD model for the sensor mounts. Print the components and make any needed adjustments.

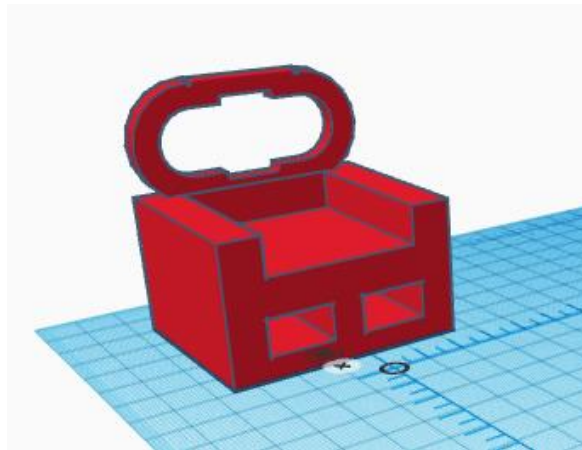


Figure 14. CAD model of MDSS.

Posterior Visual Camera System (PVCS)

Function: This subsystem mounts the camera and speakers to the back of the wheelchair using a detachable arm. The camera and one of the speakers connects to the MMVD and the other speaker connects to the CAS.

Structure: The sensors are mounted in 3D printed components which are attached to an adjustable PVC arm that uses two sizes of pipe. The arm is connected to the wheelchair using a 3D printed mount and Velcro zip ties.

Table 18. PVCS List of Materials

Material	Quantity	Cost
3D Printed PLA	7 units	\$0.00
1 inch PVC Pipe	0.25 m	\$1.43
0.5 inch PVC Pipe	0.20 m	\$1.33
¼ inch screws	2 units	\$0.00
Loomex Connector	1 unit	\$3.15
Velcro Zipties	4 units	\$0.80
ABS Glue	>1 container	\$0.00
Camera and Speaker System	1 unit	\$29.99
	Total Cost	\$36.7

Table 18 displays the materials used to build the PVCS system with their corresponding cost per one system.

Subsystem Assembly Process: This subsystem was assembled using the following steps:

1. Buy the necessary materials.
2. Cut the PVC pipes down to size.
3. Using the lathe machine, trim the size of the ½ inch PVC to fit in Loomex Connector.
4. Design a CAD model for the sensor mounts, camera mount and bar attachments. Print the components and make any needed adjustments.
5. Using ABS glue, attach the 3D printed components and the Loomex Connector to the PVC piping.
6. Attach the camera and speakers using the provided screws.



Figure 15. PVCS sub-system.

Main Medial Visual Display (MMVD)

Function: This subsystem displays the image captured on the camera in the PVCS to the user on an adjustable arm.

Structure: The display arm is attached to the wheelchair using a 3D printed hinged Velcro attachment and the display is mounted on an adjustable gooseneck.

Table 20. MMVD List of Materials

Material	Quantity	Cost
3D Printed PLA	4 units	\$0.00
1 inch PVC Pipe	0.20 m	\$1.15
1 inch screw	1 unit	\$0.00
Gooseneck	1 unit	\$29.85
Velcro Zipties	2 units	\$0.40
ABS Glue	>1 container	\$0.00
Display	1 unit	\$23.99
	Total Cost	\$55.39

Table 20 displays the materials used to build the MMVD system with their corresponding cost per one system.

Subsystem Assembly Process: This subsystem was assembled using the following steps:

1. Buy the necessary materials.
2. Cut the PVC pipe down to size. See drawing in Appendix II.
3. Design a CAD model for the hinge and display mount. Print the components and make any needed adjustments.
4. Using ABS glue, attach the 3D printed components and the display.
5. Attach the gooseneck to the PVC pipe using the built-in screw-tightening feature.



Figure 16. MMVD sub-system.

8.4 Prototype II assembly process. The assembly process of prototype II took place in three stages:

Stage One: Individual Sub-System Assembly

In this stage, all of the five subsystems were assembled according to their task list. Each subsystem was tested at various points during this stage to ensure stage two assembled.

Stage Two: Spray Painting

As all of the components were differently coloured, the structural components of all the subsystems were spray painted a uniform black. The purpose of this was to improve on the aesthetics of the project.

Stage Three: Subsystem Assembly

In this stage, all of the subsystems were wired together. Since the structures were assembled as a part of the stage three, no further structural assembly was required.

Further Assembly:

As the system was designed for any wheelchair, further assembly is required in order to install the product onto a wheelchair.

- The assembly process includes the following steps:
- Attach the bars to the wheelchair: All of the bars use a self-supporting Velcro-attachment system. Therefore in order to install these structures, the Loomex connector must be adjusted to account for the size of the wheelchair to which the bar is being connected. Then, the zip ties need to be wrapped around the wheelchair bars and tightly secured. Since the wires are connected together at this stage, the wires must also be positioned when attaching the bars.
- Attach the MDSS Sensor Mounts to the foot rests: The sensors are mounted to a 3D printed component which connects to each foot rest using a Velcro Zip-tie.
- Attach the display arm: The display arm is attached to the right front arm rest of the wheelchair using a similar Zip-tie system to the MDSS.
- Wire the Arduino: The wires are transported separately to the Arduino unit. Therefore the pins must be connected into the Arduino unit and the power cable must be connected from the battery to the circuit card. Please see Appendix II for the circuit diagram.
- Wire the Camera: The rear view camera, sitting on-top of the main bar, wires to the battery located in the CAS using a power cable, wires to the display in the MMVD using a video input cable and wires to the speaker also located in the PVCS.

8.5 Validation. Our design was validated by both testing and by our client. Although tested at various points during assembly, the final prototype II was tested and worked with full functionality. Furthermore, on the design day, the client provided feedback on the final design and seemed to be satisfied with the final product.

9.0 Project Summary and Recommendations for Future Work

In order to design a system for a wheelchair that indicates the surroundings to user with limited spatial awareness and alerts the user to obstacles, we decided to use a design thinking process. The first stage of this project therefore entailed interviewing the client in order to formulate an understanding of both their problem and needs regarding a solution. From this a problem was defined in the next stage by forming a problem statement, benchmarking and defining metrics and target specifications. In the next stage this information was used to form design criteria and ideate based on this. To create the final solution, individual solutions were formed and compared against the design criteria using a design matrix and then the best of the individual concepts were compared in the same way. Although close to the client's wants, due to client feedback we added extra sensors to this design to further solve the problem. From here, low-fidelity prototypes were built and tested until a final high-fidelity prototype was built. This final model was tested against the criteria and client.

During the secondary prototyping process, we divided the work between two main teams based on program expertise. The computer and software engineering partners, Ivan and Quang-Vinh, were responsible mainly for the completion of the electronic systems while the mechanical engineering students, Nathalia and Raveen, were responsible mainly for the structural subsystems. Upon completion of individual tasks, the system was assembled.

The electronics team was responsible for coding the logic of the Arduino board and intern the behaviour of the system as well as all the wiring of the electronics which includes the 4 sensors and the rear-view camera. In order to complete this task, they wrote code that would display the data gathered by the sensors before they arrived so that each sensor could be tested in case they were faulty and have to order another and to check our code. All sensors worked and adjustments to the code were made to incorporate all four sensors. Then all four sensors were tested together but quickly realized that the wiring would take up 16 slots on the Arduino board and the board only had two vccs and two gnds. Through research and some intuition, the redundant inputs of the sensors were wired together. This simplified the code saved on wire and increases simplicity. This new system meant measurements and solder joints were redone and the wiring material was changed in favour of a cable in order to increase connection strength. In future prototypes this cable would be run through the pvc pipes and all wires would be contained in cable sleeves to improve on aesthetics.

The structural team was responsible for the structural elements that the electronics would attach to. This included a bar at the back comprised of two pvc pipes of varying diameters, to allow for adjustment, connected with a Loomex Connector. These bars would act as a mount for the rear-view camera and speakers as well as the Arduino board and battery and is where all the wiring would meet. Similar bars were made to fit under the armrests to mount the side sensors and individual mounts were made to fit sensors under the foot rests. Furthermore, a hinge was 3-d

printed to hold the rear-view camera screen. In future projects, the pla used in the 3D printing would be replaced with a stronger material, such as ABS, to increase the strength of connection points. Furthermore, prints would be adjusted to change the style of the bar attachment model. Although the model is functional, it is not universal to all wheelchairs. A hook method, instead of the push method, of attachment would favour better and would use the same construction concept of 3D printing.

Therefore, in future iterations, detailed schematics of both the complete system as a whole as well as wiring would be made to improve aesthetics, reliability, ease of use, and coordination. Also, higher quality 3-D printer filament and wires to improve reliability, usability, and quality of the product. This would require regular meetups between teams to track progress, discuss issues, update schematics and run preliminary testing of the system together to foresee problems or make improvements.

In conclusion, the solution iterated by this design group addresses the issue of creating a wheelchair driving aid to increase a user's spatial awareness and their ability to avoid obstacles. Future iterations of this project aimed to increase strength and degree of aesthetics would put this design into a finality which could lead to further production and sales based on a business model.

References

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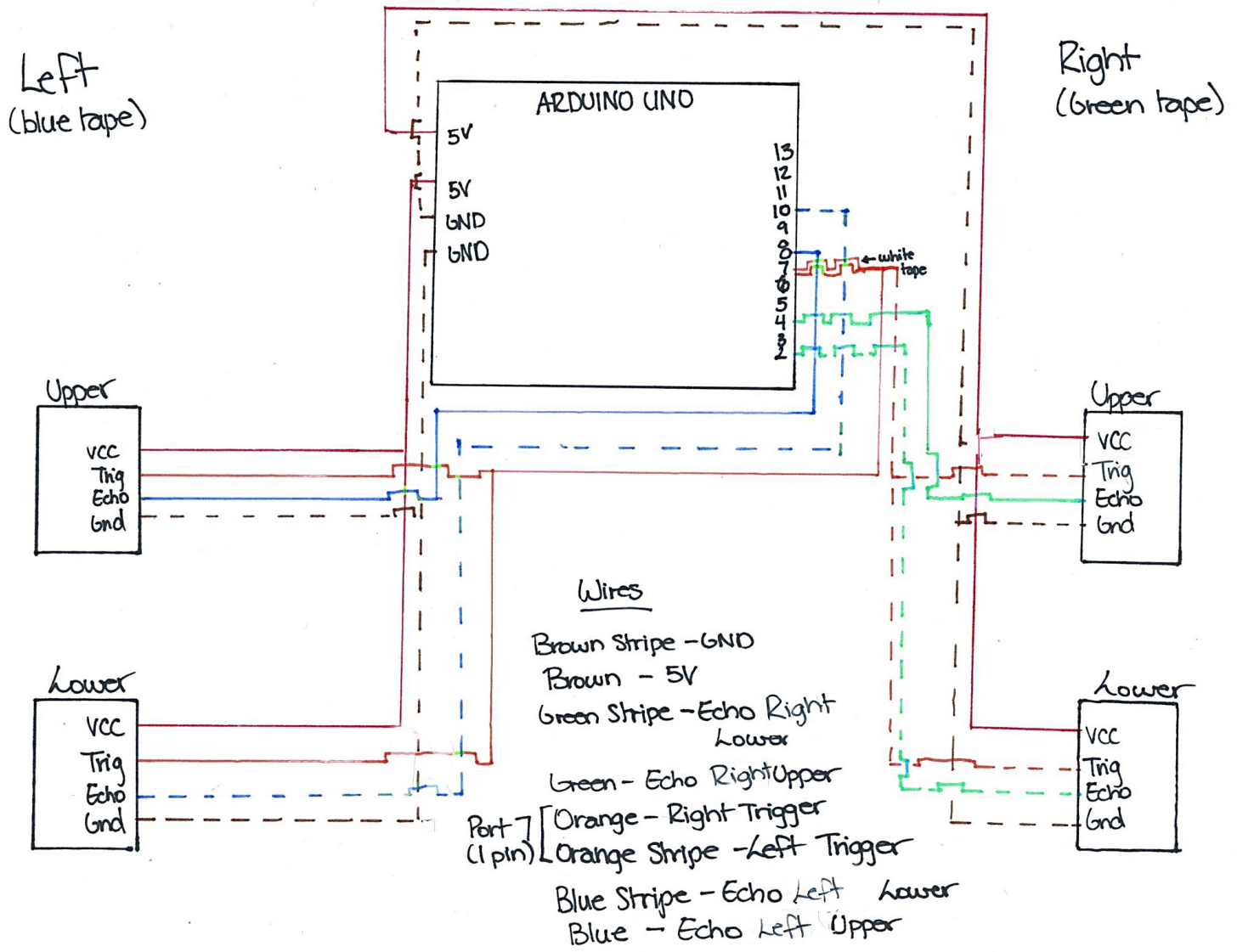
Appendices

I: Meeting Schedule

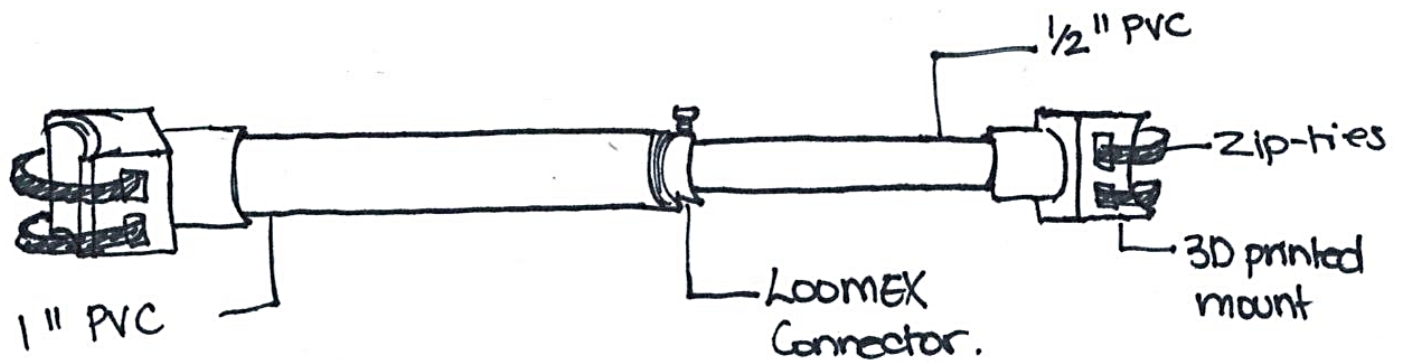
Date	Time Spent	Activity
09/09/2017	5:30pm - 6:30pm	Team Contract Formation: completing contract
09/11/2017	7:00pm-8:00pm 50 min 10 min	Team Contract Formation: <ul style="list-style-type: none"> • Discussing and picking top 3 projects • Signing the contract
09/18/2017	7:00pm-7:15pm 10 min 5 min	Project Selection <ul style="list-style-type: none"> • Ticket Purchase and Selection • First interview discussion
09/20/2017	9:30am - 11:00am	First Client Interview (See Notes)
09/27/2017	4pm-5:30pm	<ul style="list-style-type: none"> • Problem Statement formation • Individual Solution presentation • General solution creation
09/29/2017	1:30pm-2:15pm	Interview with Boar (over phone) - Nathalia
10/04/2017	4pm-5:30p	<ul style="list-style-type: none"> • Design details
10/11/2017	9:30am-10:30am	<ul style="list-style-type: none"> • Feedback from Bocar and Phil
10/11/2017	4:00pm-5:00pm	<ul style="list-style-type: none"> • Project Plan Discussion • Discussion of Prototype I
11/01/2017	4:00pm-5:30pm	<ul style="list-style-type: none"> • Business Model Finshing • Validation Board Planning • Creation of Survey
11/08/2017	9:30am-10:30am	<ul style="list-style-type: none"> • Prototype I Review With Client
11/15/2017	10am-11:30am	<ul style="list-style-type: none"> • Prototype II Discussion
11/22/2-017	8:30am-11:30am	<ul style="list-style-type: none"> • Work on Subsystems at makerspace
11/22/2017	4pm-5:30pm	<ul style="list-style-type: none"> • Film Video Pitch • Discuss Economics Report
11/25/2017	12:00pm-7:00pm	<ul style="list-style-type: none"> • Work on Subsystem completion at Makerspace and Brunsfield

II Technical Drawings

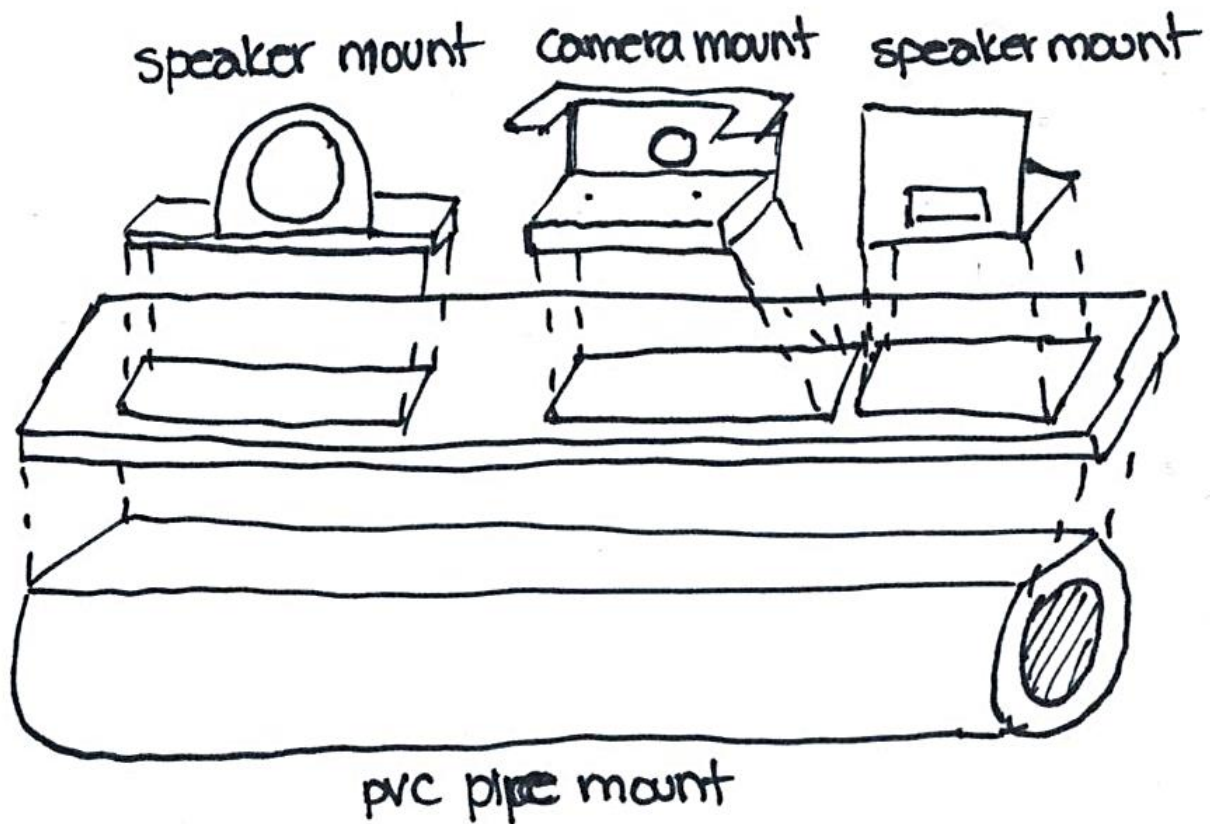
II.I CAS Wiring Schematic



II.II Bar Attachment Design



II.III PVCS Mount Design



II.IV MMVD Design

