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Intelligent Sensation and Eyesight Emulation Unit (ISEEU)

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Abstract

In the last few decades numerous attempts have been made to aid the visually impaired with smarter technologies for better living. These assistive technologies have focused on various areas from path detection to face recognition. Our project aims at addressing the mobility and orientation needs of the millions of visually impaired people across the world. They face numerous problems with mobility and navigation every day, including bumping into objects and falling from stairs. Existing mobility aids for the visually impaired are mostly unreliable, unaffordable or have many limitations on the users and their environments. Eliminating these limitations while better addressing the everyday mobility problems of the visually impaired is our motivation to build our product ISEEU (Intelligent Simulation and Eyesight Emulation Unit). Our product aids the user in obstacle and path detection using haptic feedback, the sense of touch. The end product of our project is a portable belt that can be worn comfortably around the waist. The belt comprises of multiple vibrating devices which vibrate to inform the user of the direction and relative distance of the approaching obstacles. Thus, ISEEU serves as an affordable, portable and intuitive solution to the mobile needs of the visually impaired.

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  We got inspiration from her to brainstorm and implement an assistive device for visually impaired people. She was the main reason that we decided to take this on as our fourth year design project.

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1. High Level Description of the Project

1.1 Motivation

Our motivation behind this project came from a team members' blind grandmother. She is only one of the 285 million people that are visually impaired around the world [1]. The feedback from her has largely influenced the design and functional requirements regarding this project. Problems like bumping into objects and falling down stairs were her biggest concerns.

The most conventionally used navigation aids include walking canes, guide dogs and personal guardians. However, these navigation methods can be costly, unreliable or inconvenient. For example, guide dogs cost can cost up to $42,000 [2] to raise and take up to eight months on average to train. Even non-profit organizations such as 'Canadian Dogs for the Blind' would need some way to offset these costs. More recent assistive systems using methods like sonar have been developed to aid these people, but most of them are either unaffordable or have many limitations on the users and their environments.

1.2 Project Objective

Our goal is to build a system on a belt to make the user independent and more aware of the people and objects in their environment.

1.3 Block Diagram

The ISEEU system is composed of five main subsystems as shown in Figure 1.

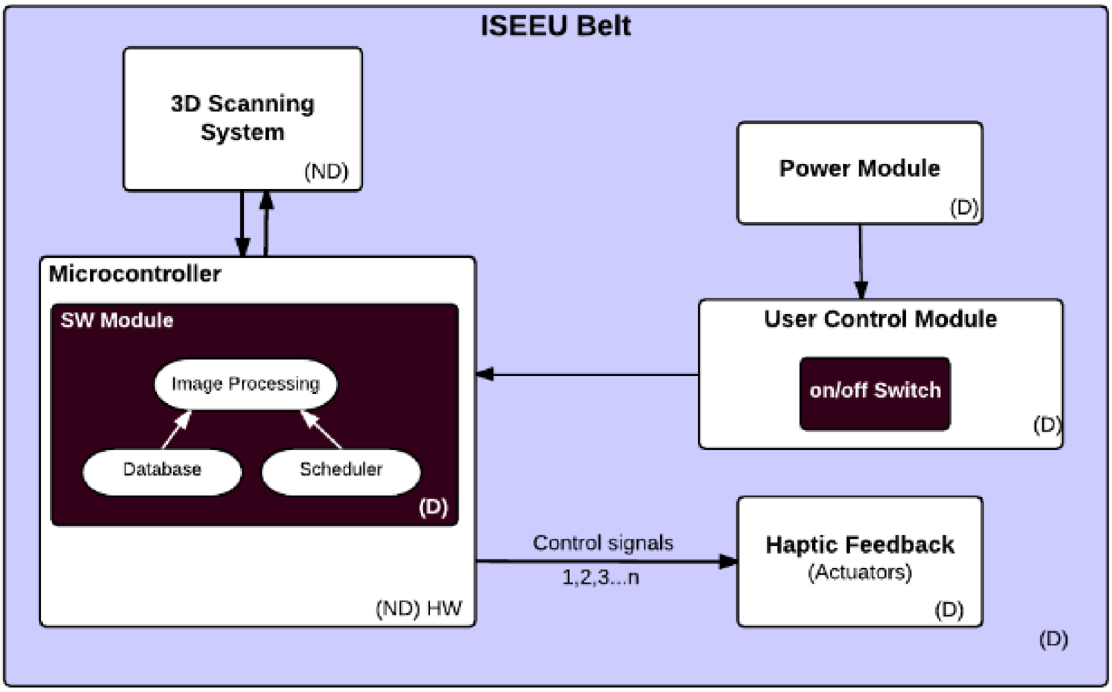


Figure 1: Block Diagram of the ISEEU system (*D/ND - Design/Non Design)

The 3D scanning camera takes an image of the front view of the user and generates a data set containing a 2D array of Cartesian coordinates with associated depth information.

These data sets are generated periodically at a certain frequency (e.g. 30 frames per sec) and the information associated with the most recent data set is stored in the database at any given instant. The information contained in the database is then processed by the Image processing unit to evaluate the proximity and direction of any object in front of the user. The scheduler is a component that ensures that the Xtion camera becomes functional and starts collecting data for the image processing unit when the microcontroller boots up. The image processing unit along with the database and the scheduler, are all a part of the Software Module which is purely a design component loaded onto a non-design microcontroller. The changes reflected through the computations by the Software Module are then conveyed to the user through the haptic feedback subsystem in the form of vibrations. The intensity and location of vibrations varies with the distance between the user and the object and the direction the object is approaching from. The power module subsystem is responsible for powering up the microcontroller subsystem, which further provides power to the 3D scanner subsystem and sends control signals to the Haptic Feedback subsystem. The user control module subsystem is an interface for the user to control the operation of the entire system. It consists of a switch that gives user the control to turn the entire system on/off.

All these subsystems are installed on a single, portable belt that can be worn around the waist by the user. The design of the belt incorporates the casing and positioning of the components and the fabric for the belt. Thus the belt encompasses the final system.

1.4 Part Listing

Table 1. Part Listing - Components used and their manufacturers

Component	Manufacturer/Distributor
Actuators - Eccentric Rotating Mass actuators	SolarBotics model number: 2645-CA1
3D Scanner - Xtion PRO LIVE	Asus
Microcontroller – UDOO	Digi-Key
Battery - Lithium Ion	Samsung Romoss
Belt - Valeo Low profile lifting belt	EB Sport Group

2. Project Specifications

This section lists the functional and non-functional specifications of the project. The table2 provides a brief summary of the specifications and their classification.

Table 2: Classification of Project Specifications

No	Specifications	*E/NE	*FN /NFN	Subsystem
1	Battery life should be at least 2 hours	E	FN	Power
2	The intensity of the vibrations for the haptic feedback should vary with the range of distance of the object from the user on a scale of at least 3 - Low (600mm <r < 1m), Medium (1m < r <2.5m), High (4m < r < 2.5m)	E	FN	Software
3	System should be able to differentiate between objects located on left, center and right of the user's front view	E	FN	Software
4	System should support at least 3 actuators in each direction for object detection in that direction.	E	FN	Haptic Feedback
5	The user should be able to choose between three different ranges of intensity	NE	FN	User -Control
6	Weight of the system should be less than 1kg	NE	NFN	ISEEU Belt
7	The cost of the end product should not exceed $700	NE	NFN	ISEEU Belt

* **E**/NE - Essential/Non Essential; FN/NFN – Functional /Non-Functional

2. 1 Functional Specifications

1. Specification Statement: *"Battery life should be at least 2 hour"*
Explanation: The goal of the project is to help a visually impaired person to feel the environment around them independently for long periods of time. Thus, a crucial functionality that our system needs to support is a long battery life and avoidance the hassles of charging the system for as long as possible.

Verifiable: The verification of this specification should be trivial however it requires the verifier to run the system at its full capacity for at least 2 hours.
Open-ended: This specification is open ended since there are many battery options available for supplying power to the system.

2. Specification Statement: "*The intensity of the vibrations for the Haptic Feedback should vary with the range of distance of the object from the user, on a scale of at least 3 - Low, Med, High*"
Explanation: The project not only aims at making the user aware of any objects approaching the user but it also aims at giving the user an idea of the proximity of the approaching objects. In order to achieve this, our system must support different levels of vibration intensities. The way it works is that the distance between the user and the object is discretized into three

zones, and each part is then associated to one level of intensity. For example, the user will feel light vibrations for any objects at a distance of 2 m or more, a medium intensity of vibrations for any objects between 1m to 2m and a high intensity of vibrations for any objects closer than 1m.

Verifiable: This specification is easily verified once the prototype is ready. For example, three arches can be marked at a radius of 1m, 2m and 3m from a "center" point. The user who is also the tester in this case can be positioned at this center point. One of the students can help to verify this specification by alternatively stepping back and forth between the different zones marked by these arches. This should result in appropriate changes in vibration intensities on the belt at the user/tester end.

Open-ended: Different kinds of vibrating devices support different ranges of vibration intensities. The allocation of vibration frequencies for a certain zone will depend on the range of frequencies supported by the device picked.

3. Specification Statement: *"System should be able to differentiate between objects located on left, center and right of the user's front view"*

Explanation: This specification gives the user another level of the proximity of the approaching objects. The system should be able to differentiate the objects in three different directions: left, right and front. In order to achieve this, the vibration location on the belt should vary according to the direction of the objects. For example, from the camera's view, the software module designates 20 degrees for each of the left, center and right direction.

Verifiable: This specification is easily verified once the prototype is ready. Three lines can be drawn from the stationary user to specify the three different directions. The user who is also the tester in this case can be positioned at this center point. One of the students can help to verify this specification by alternatively stepping left and right in between different lines. This should result in appropriate changes in vibration location on the belt at the user/tester end.

Open-ended: The algorithms used to determine directions implemented in the software module could vary. Also, the degrees that can be assigned to each direction can vary.

4. Specification Statement: *"System should support at least 3 actuators in each direction for object detection in that direction"*

Explanation: The reason for choosing three actuators in each direction was to ensure that the combined strength of vibrations is substantial enough for human recognition. Moreover the reason for choosing the number "three" was to provide a backup in case of failure of one of the devices.

Verifiable: The tester can easily verify this by counting the number of vibrating actuators when an object is detected in a certain direction (left, center, right).

Open-ended: The criterion for deciding the number of actuators is open ended because the number might still change based the strength of vibrations produced by each actuator. This will be verified and number will be finalized after the arrival of the ordered actuators.

5. Specification Statement: *"The user should be able to choose between three different ranges of intensity"*
Explanation: Initially it was planned to allow the user to be able to select the range of vibration intensity which would be comfortable for them. The selected range was then to be divided in three sub-ranges for detecting the objects at a small, medium and large distance using low, medium and high intensity of vibrations. However, it was later decided that choosing a range of vibration intensity would be very difficult and confusing for a visually impaired person. Therefore this non essential specification was eliminated. This intensity regulator and an on/off switch were initially supposed to comprise the User Module. However, since the intensity regulator was a major part of the user module, the User Module was removed as well. It was decided to include the on/off switch in the Power Module.

2.2 Non-Functional Specifications

1. Specification Statement: "*Weight of the whole system should be less than 1kg*"
Explanation: The whole system includes a 3D scanning device, a microprocessor, a user control device, a power module and a haptic feedback module. Weight is a significant part of the design specification because the entire device should be comfortable and light. This non-functional specification is essential to our project [5].

Verifiable: This is easily verifiable as this is easily measurable using a weighing scale.
Open-ended: This specification is open ended because there exist many different alternatives for different modules and different material alternatives exist for making the belt in order to optimize the comfort and weight.

2. Specification Statement: "*The cost of the end product should not exceed $700*"
The aim of the project is to provide the visually impaired people with a cost effective and affordable solution. Thus great care will be taken to ensure that the cost of the final product is minimized as much as possible without compromising on quality and efficiency. The goal is to make the final product affordable, so we aim to keep the cost of the system under $700.

Verifiable: This is easily verifiable as records can be maintained for everything that is purchased for the project. Once the components for the final prototype have been finalized, the records can be tallied to get a sum of the cost of all the components used in the final product.
Open-ended: This specification is open ended because there exist many different alternatives for different modules. Cost effective technologies can thus be chosen from a variety of options.

3. Detailed design of the system

3.1 Software Module

The software module is the core design and the brain of our project. This subsystem operates and runs on top of the microcontroller, which interacts directly with every other module. Thus this subsystem needs to provide functionality and support for the interaction of all the other modules with the microcontroller.

3.1.1 Output from the 3D scanner camera

To design the image-processing module we first had to understand how the output from the 3D scanner camera looks like. The 3D scanner camera (Xtion) consists of two units, an RGB camera and an IR (Infra-red) camera. The Xtion uses a speckle pattern of dots that are projected on to a scene (the front view of the user) by means of an IR projector and detected by the IR Camera as shown in Figure 2. Each IR dot in the speckle pattern has a unique surrounding area that allows the dot to be uniquely identified when projected onto a scene. This identification is performed by comparison with a reference image which is a pattern stored inside Xtion's memory. This reference image contains the same IR speckle pattern when projected on a completely flat surface.

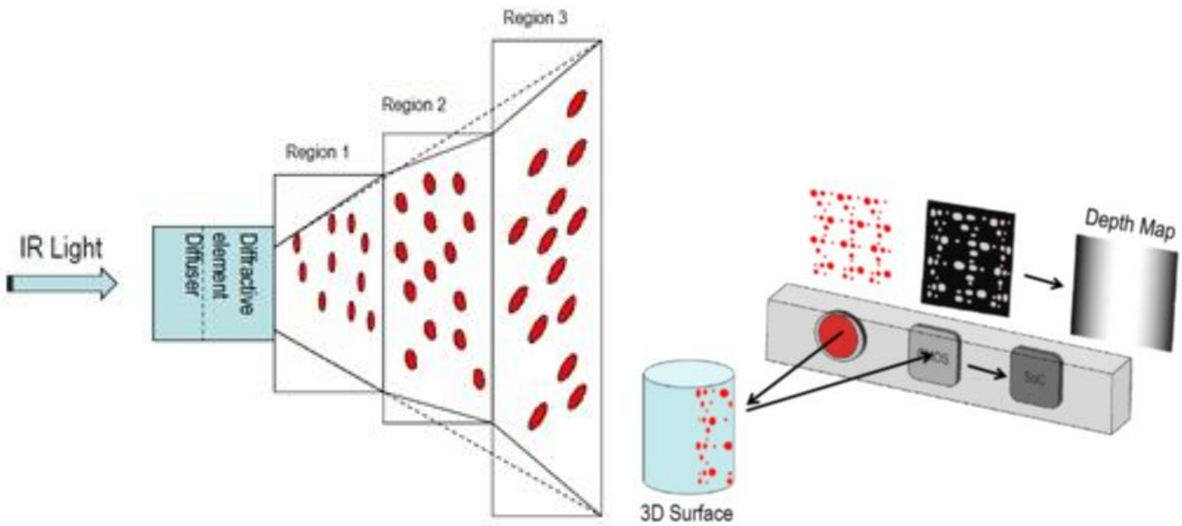


Figure 2: Speckle output from the IR camera [3]

The inbuilt mathematical algorithm picks a particular dot in the reference pattern and then looks for that dot in the observed scene. Once a dot is identified in the scene, its disparity (the difference between the size and shape of the projected IR pixel as compared to the reference pixel) can be determined. The disparity, in conjunction with the focal length of the IR camera is used to detect the speckle pattern and the baseline between the projector and the camera to determine the depth of that point. The output from the Xtion is thus a collection of multiple points with their associated x,y coordinates and depth.

3.1.1 Implementing the software module

The aim of the software module is not only to gather information generated by the IR camera (coordinates and depth information), but also to process this information in order to detect the direction and proximity of the obstacles. Several design iterations were performed before finalizing the design of this module.

Design logic for Object Detection

Iteration 1:
In order to detect any obstacles in the front of the user using Xtion, the following design was initially proposed. As discussed earlier, the pixel data that is received from the Xtion is in the form of a 2D array of size 640 Horizontal (H) x 480 Vertical (V) by default, at 30fps.

- For the first iteration we decided to divide the original array of 640 (H) x 480 (V) pixels into blocks of smaller arrays, say of size of 40 (H) x 48(V) pixels, as shown in figure 3. Thus each small block consisted of 1920 pixels resulting in a total of 16x10 blocks of the entire field of view.
- Since a depth is associated with every pixel data, the depth of each block is determined by calculating the average depth of all the pixels within the block. Moreover, the (x,y) coordinates of the center point of that particular block were chosen to refer to any data associated with the pixels in that block.
- A 2D array would then store the data computed in step two, which would comprise of the coordinates and the depth of each block. For naming purposes let us call the array created in this step as "*previous_array*".
- Similarly, the data associated with next frame would be processed and stored in another 2D array, which can be called *"current_array*" for naming purposes. The *current_array* would be used as a reference against the *previous_array*.
- Depth of each element in the *previous_array, "*PrevArray[i][j]" would be compared with the depth of the corresponding elements in the *current_array, "*CurrArray[i][j]". The results obtained would then be used to perform the following computation and analysis:

```
depth_diff   =   CurrArray[i][j] - PrevArray[i][j];

if          depth_diff > 0  && PrevArray[i][j] = 0       // Object is detected
else if     depth_diff > 0 &&  PrevArray[i][j] != 0      // Object moving away
else if     depth_diff < 0 &&  PrevArray[i][j] != 0      // Object moving closer
else if     depth_diff < 0 &&  CurrArray[i][j] = 0       // Object really close
else if     |depth_diff| < = 100                         // Stationary object
```

In the pseudo code above, the "depth_diff" is the difference of depths between the corresponding elements in two consecutive frames. If in a certain direction, Xtion is unable to detect any objects up to a distance of 9m, it reads the depth in that direction as 0. The optical range of Xtion is a sector of a circle with radius 9m and angle 58 (approximated by 60 for ease of design) degrees as shown in figure 5. Thus initially if the user is surrounded by nothing in the optical range of Xtion, the depth of all small blocks will be zero. The moment someone enters the optical range of Xtion, the depth of some of the blocks will become positive. Thus, the first if statement shown in the pseudo code above takes care of this case. If the object starts to move towards the user, the depth will be a constantly decreasing number, hence depth_diff will be negative. Similarly, if it is moving away the depth will be a constantly increasing number, thus depth_diff will be positive. Another point to be noted here is that Xtion is unable to detect any objects that are any closer to it than 60cm. In this case too, it detects the depth of this really close object as zero. Thus the one but last if statement in the pseudo code takes care of a case when an object was approaching the user and then comes really close to the user. In this case when user comes closer, the depth constantly decreases and at a point the depth suddenly becomes zero. The last else if statement takes care of the case when the user is stationary but there is a stationary object within the optical range of the Xtion. Very small changes in depth are thus neglected and if the depth changes in an object's location are less than 1cm, it is assumed that it is stationary.

<u>Iteration 2:</u>

In this design iteration, we decided to take the object detection to a next level by including the information about the direction of object detected relative to the user. To achieve this we built upon the design of iteration 1 in the following manner:

As discussed in Iteration 1, a 2D array of 16 x 10 blocks would be created. To determine the direction of obstacles we decided to divide these blocks into three parts corresponding to three different directions (i.e., left, center and right). This leads to the formation of three regions with each containing the following number of blocks as depicted by figure 3: Left – 16 x 4; Center – 16 x 2; Right - 16 x 4. Each block thus has a unique center point and an object is detected in a certain direction only if the depths of at least 10% of the blocks in a region/direction have changed.

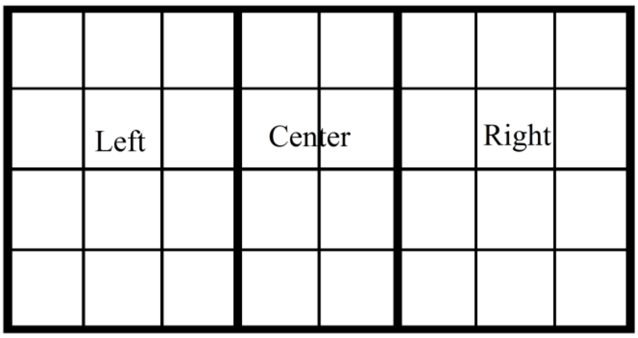


Figure 3: The three regions and sub blocks

The division of blocks shown in Figure 3 is achieved using the logic depicted in the following pseudo code:

```
tmp_iterator = i % (pDepthMD->pMap->Res.X);

if  (tmp_iterator  <= (pDepthMD->pMap->Res.X)/3)
 {
        // Add the point to the left Block
}

else if ( tmp_iterator  <= 2*(pDepthMD->pMap->Res.X)/3
        && tmp_iterator > (pDepthMD->pMap->Res.X)/3 ) )
{
        // Add the point to the left Block
}

else if( tmp_iterator  > 2*(pDepthMD->pMap->Res.X)/3
        && tmp_iterator <= (pDepthMD->pMap->Res.X) ) )
{
        // Add the point to the left Block
 }
```

In the pseudo code above, 'i' is an iterator that helps to iterate through all the points in the incoming stream of data.

<u>Iteration 3:</u>

In the next iteration we decided to club smaller blocks in each of the three regions. This resulted in three big sub arrays as shown in Figure 4.

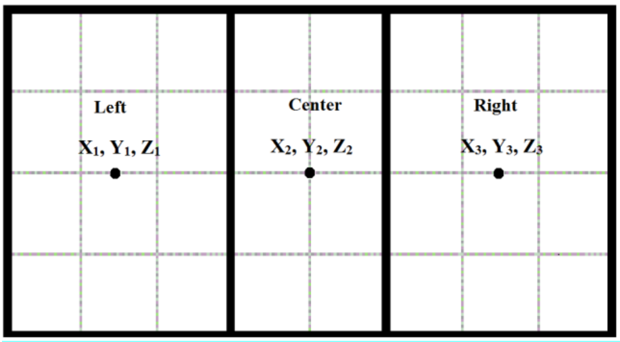


Figure 4: The three regions with coordinates and depths

This can be viewed as if the front view of the Xtion (58 degrees horizontal) camera has been divided into three parts (each of about 20 degrees as shown in figure 5) in order to detect the location of the obstacles relative to the user. The (x, y) coordinates used to identify the left region is the central point of the left region and the depth of left region is the average depth of all the pixels within this region. Similarly for right and center regions, an (x, y) coordinate and depth are associated using their respective centre points for depth for coordinates and the average depth of all the pixels within their respective regions. If the depth of any of these regions changes by 10% of its previous value (value in *previous_array)*, it is concluded that an object has been detected in the direction associated with that particular region.

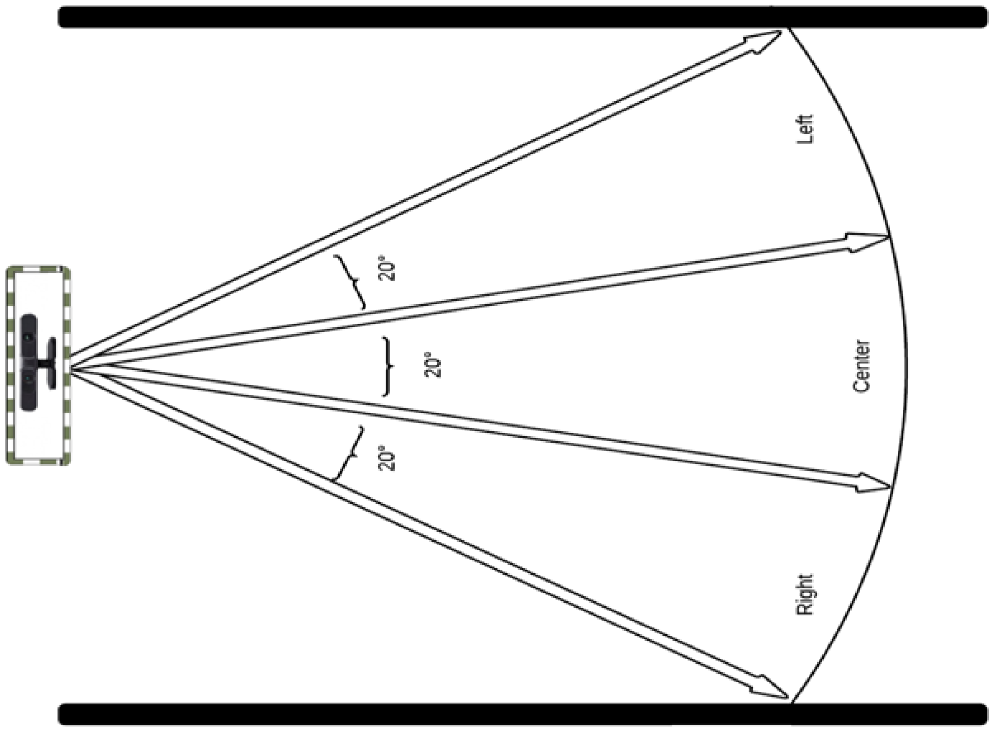


Figure 5: Three regions/angular division for direction

Iteration 4:

In this iteration we decided to implement another important feature that is to detect the proximity of the object relative to the user. In order to calculate the proximity of the object, the range of the optical view of the 3D scan camera was divided into three regions as shown in Figure 6.

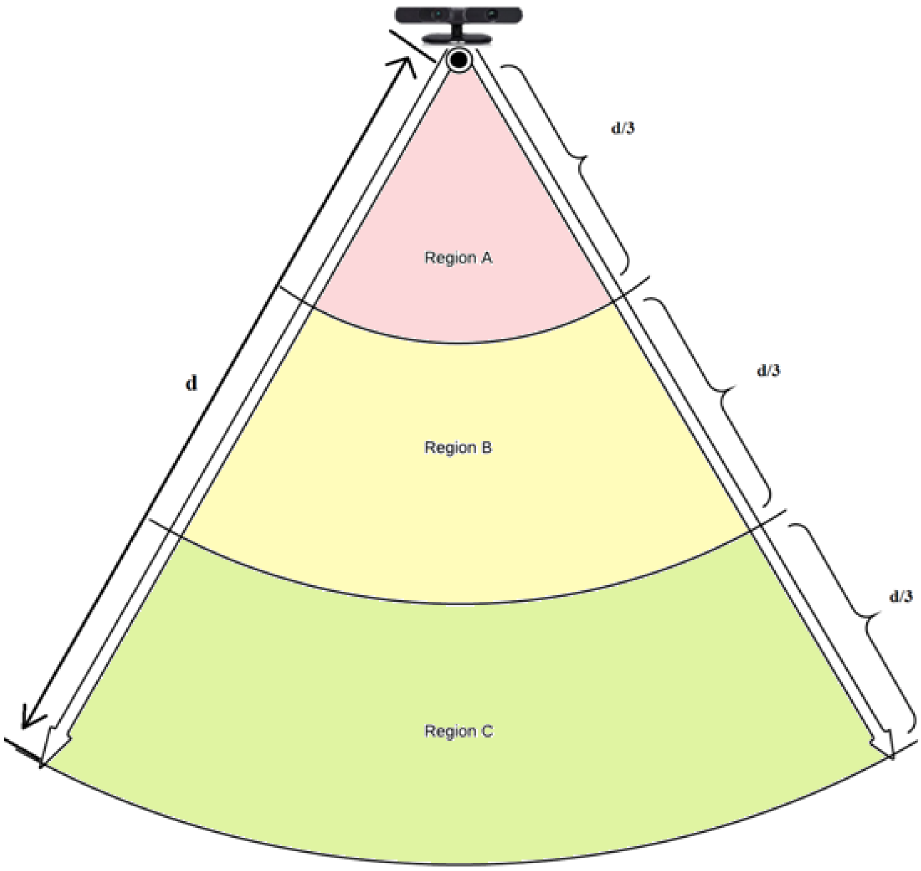


Figure 6: The three regions in front view of camera

The regions shown above are the areas enclosed by arcs marked by the radii shown in Table 3.

Table 3: Regions based on depth of the object detected by Asus

Region a: 0 < r < d/3	Region B: d/3 < r < 2d/3	Region C: 2d/3 < r < d

Here, d is the maximum range up to which the system detects objects.
For the purpose of creating a realistic product we chose d as 4m. This is because our product is designed to be used indoors and thus providing information with the 4m range is enough for the purposes of this project. The probability of the presence of large number of objects within a few meters from the user is very high. Hence a smaller value of d helps in limiting the noise that is generated by the far off objects.

At a given point of time the depth of an approaching object will lie in any one of the regions shown in Table 3. The software module is programmed in a way to send 3 different signals to the haptic feedback module based on this depth. Larger the depth value, lower is the magnitude of current that is sent to the haptic feedback module. This lower current thus produces low intensity of vibrations. So when the object is in the far region, region C, the user feels a lower intensity of vibrations. As the object comes closer, that is moves from region C to A, the intensity of vibrations increases.

Iteration 5:

After testing our product in a real world environment we discovered a fundamental problem with our implementation. We found out that the actuators were only vibrating when a movement in the object in front of the user was detected (assuming the user is stationary). This was because the idea so far behind the implementation was to take a difference of the depths associated with current and previous frames. In the case when the user as well as the object in front of the user is stationary (assuming no other movements in the surrounding environment), no changes of depths were detected in the current and previous frames. Hence the stationary object was not reported. This was an important concern for us as developers, since it defeated the very purpose of the project, which was to make the user aware of their surroundings. Thus this inspired us to come up with an improved design for our product, which would solve this problem.

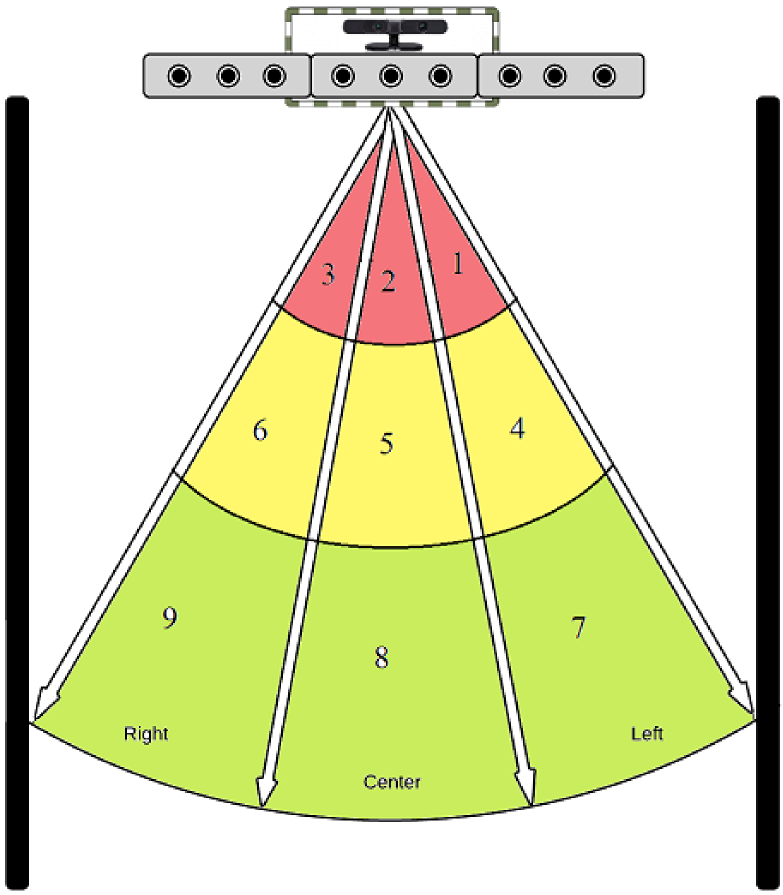


Figure 7: Depiction of all the 9 regions corresponding to each actuator

We decided to build up on the previous implementation to find a solution to the problem stated above. Since the front region was already divided into nine regions (as before) and we decided to make the user aware of the proximity of the object/person, based solely on this information. So consider the case where someone is approaching the user from the left direction. By approaching the user we mean, the person starts at the far region, then moves to the closer region and ultimately moves to the closest region. In Figure 7, this will be the path from Region 7 to region 4 to region 1. For this particular case, in earlier implementations from the previous iterations, the average depth of the left block would constantly decrease. Using this information the intensity of vibrations (for each actuator on the left) would hence be increased to indicate the approaching user. However, in the new implementation the intensity of vibrations will increase only when the person in the front moves from one colored region to another. When the person is in the farthest region on left (region 7) only one actuator vibrates on the left side of the user. As the user comes closer and enters region 4, two actuators start vibrating, giving the user a sense of increased vibration and indicating that someone is coming closer, or is in a fairly close proximity to them. Similarly, in the nearest region (region 1) all three actuators vibrate, giving the user a sense of a more increased vibrations and thus letting them know that somebody/something is really close to them. This design thus helped to solve the previous problem of not being able to detect stationary objects/people when the user is stationary. At the same time it retained the previous functionality of letting the user know of any approaching objects/people by increasing the intensity of vibrations.

Iteration 6:

As we continued our testing of our product, we discovered another major issue with our design. Our initial intent was to make the user aware of the object that is nearest to them, since it would be more important for a visually impaired person to be informed about the objects closest to them at any given instant. Through various tests we found out that we were getting erroneous results for the case when a small object was present in front of a relatively large object. For example, consider the case when a person is standing in front of a wall in the center region. According to the current implementation an average of the depths of all the pixels would be taken in a certain direction. It was found that if the user stood without a wall behind them, the averages of all pixel points would indicate that the user is within far, near or nearest region. However when the wall was present, the user was informed about the presence of the wall instead of the presence of the person standing in front of the wall who was nearer to the user. After analyzing our implementation, we realized that since we were taking the average of the pixels in the blocks, the larger objects would always get more weightage in the calculated average as compared to the smaller object. Hence the user would always be informed about the largest object present in front of them rather than the nearest object. We thus decided to conquer this problem using our knowledge of advanced algorithms gained through the ECE457a course. There were many advanced algorithms that could be used for implementing the functionality of finding the nearest object. We decided to use Simulated Annealing for solving this problem, primarily because it yielded optimal results in minimal time as compared to other advanced algorithms such as 'Genetic Algorithm' and 'Particle Swarm Optimization'.

Background of Simulated Annealing algorithm:

This algorithm is an optimization process based on the Physical Annealing procedure. Annealing is the process of heating a material above its crystallization state and then gradually letting it cool to recrystallize itself into a minimum energy state. Simulated Annealing is the algorithmic equivalent of this process. The aim of the algorithm is to help find the minimum most value of the objective function by exploring alternative solutions that help improve (minimize) the value of the objective function. Just like the initial state of the system in physical annealing, this algorithm has an initial value of the objective function using some initial solution. As the temperature is lowered and hence energy of system lowered with time in physical annealing, this algorithm accepts any new solutions that can help attain a lower objective function value. Lastly the process is terminated when the material crystallizes and freezes at a state of lower most energy. Similarly the algorithm terminates once it has attained a final most optimal solution for the objective function.

Implementation details for Simulated Annealing algorithm:
As mentioned earlier, the camera operates at 30 frames per second and each frame contains 640 by 480 pixels of data. This algorithm aims to find an area with minimum depth in the three sub-blocks (each corresponding to one direction) in front of the user.

The algorithm starts off by selecting 10 random points in one of the three sub-blocks. A subset of these points which have the minimum most depth are then selected for further study. The pixels around each of these points in the subset are further analyzed and their average depths are taken. The region with the minimum average depth using the Simulated Annealing algorithm and is then selected to alert the user about the object in that sub-block (direction). This is then repeated for the other two sub-blocks.

We ensured that the area studied around each pixel is at least one-fourth of the total area of the sub-block. The reason why we chose to analyze one-fourth of the area was because we wanted to only report objects of significant size to the user.

Iteration 7:
After running the implementation achieved in Iteration 5, we realized that there were some significant delays in sensing the object location in front of the user as compared to the previous implementations. It took nearly 0.4s to print information related to a single frame's data. This was significantly slower (nearly 10 times) than the rate at which we were receiving the frames, that is 30 frames per second, which meant we had only 0.03s to process each frame's data.

We decided to make use of our knowledge of parallel programming, that we had earned in ECE459 course to find a solution to this problem. Parallel programming was an obvious choice to speed up the program because of the nature and the structure of our software design. The computation to detect an object on left is completely independent of the computations performed for the center and right directions; thus these computations could very well be run in parallel.

In order to parallelize our code we decided to make use of the threads in C++ from the standard library. Threads were chosen over processes because threads have much lesser overhead for creation as compared to processes. Each of the threads was hence responsible for finding the nearest object in only one direction; one thread for left, one for right and one for center, using the advanced algorithm implementation mentioned in iteration 6.

Thus, at this point we had narrowed down the problem and it was clear to us that there was no further changes needed in the implementation of the software module.

3.1.2 Functionality to support interaction of microcontroller with the 3D Camera

A requirement of our system is that it should support at least 2 hours of battery life. The main power-consuming component of our system is the Xtion camera, which needs to constantly fetch 3D scans of user's front view until the user decides to turn the system off. The rate of generation and fetching of these scans determine how much power the camera consumes. To support the requirement of 2-hour battery life we plan to minimize power losses by making the system dynamic and intelligent to consume less power when possible. Keeping in mind the fact that while a high frame rate like 30 fps can help achieve a lot of precision in tracking a fast approaching object, when the surroundings around a user are relatively stationary or are changing at a slower rate, a lower frame rate can also help achieve an equally adequate precision. The software module waits for a five seconds to check if any objects are moving towards the user at a fast rate. If yes it sends a control signal to the 3D scan camera to fetch scans at the default frame rate of 30 frames per second else a signal for fetching scans at the minimum most rate of 15 frames per second is sent. This ensures lower power consumption by the system when any fast activity is not happening in user's environment.

3.1.3 Functionality to support interaction with the Haptic Feedback Module

The haptic feedback module consists of ERM (Eccentric Rotating Mass) actuators embedded on a wearable belt, which vibrate to let the user know of any approaching objects. However as discussed earlier, our project aims at letting the user know the direction of approaching objects and their proximity from the user. For this the image processing module in combination with the software module provides the intelligence to sense the direction and record the distance of approaching objects.

<u>Iteration 1:</u>
Our initial plan was that once the direction and proximity had been determined, the software module would turn on certain GPIOs to generate PWM signals of appropriate strength and for appropriate actuators. The design of these actuators had been finalized in the iteration 1 of the Haptic Feedback Module where LRA actuators were chosen (section 3.3.4). The design decision on what signal strength was to be chosen by the PWM for the actuators is discussed below:
Larger the relative distance of the object from the user, lower would be the strength of the signal that is sent to the haptic feedback module, which thus produces lower intensity of vibrations. So when the object is in the far region the user feels a lower intensity of vibrations and as the object comes closer the intensity of vibrations increases. Thus according to the

region in which the object is detected, three voltage levels corresponding to each region are selected on the actuator performance characteristic curve. For example, in Figure 8, B1 corresponds to the lowest intensity level which corresponds to the object being located in the farthest region from the user. Similarly B2 corresponds to the middle region and B3 corresponds to the closest region relative to the user with the highest intensity level.

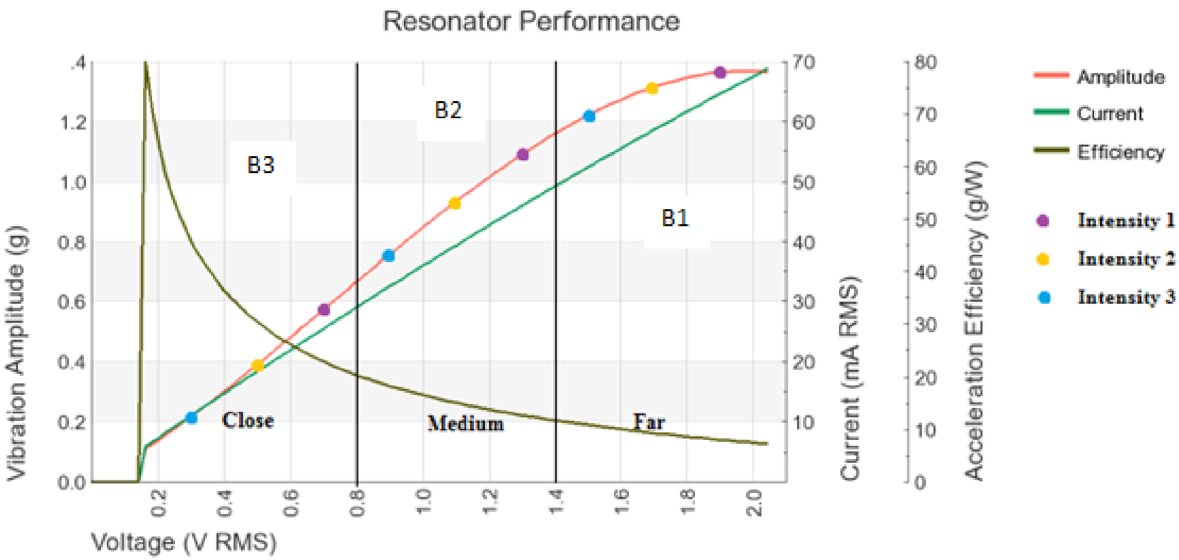


Figure 8: Depiction of intensity levels [4]

The purple and orange sets represent the same implementation corresponding to intensity levels 2 and 3 chosen by the user in the iteration1 of the user control module (section 3.4.2). These voltage levels would be set and hardcoded into the software module. Depending on the value of the intensity level chosen by the user (1, 2 or 3) the software module would return a set of three voltage-levels for PWM generation for the microcontroller. For example, for intensity level 1, the software module returns B1, B2 and B3. Similarly a different set of B1, B2, B3 would be returned for intensity level 2 and 3.

Iteration 2:

On testing the actuators with their varying vibration intensity levels, we discovered that most of vibration intensity levels are not human distinguishable. Moreover, some changes were made to the software module in order to support the detection of Stationary objects which are discussed in detail in Software Module, iteration 5 (section 3.1.1). A new method of interaction was hence chosen between the software module and the actuators (haptic feedback module). The basis of this implementation was to divide the front view of the user into nine sections; three sub blocks for each direction (left, center and right) and three sub-regions corresponding to proximity of obstacle in each direction (nearest, near and far).The nine regions are clearly depicted in figure7. Furthermore there are nine actuators in total installed on the belt, three corresponding to each direction. The idea was that in each direction, one actuator would be turned on if the obstacle is detected in the far region. Two actuators will be turned on for the near region and three for the nearest region. This will ensure that the user is made aware of any approaching objects/people by increasing the intensity of vibrations.

Thus in this iteration, nine GPIO pins were allotted to each of the nine regions. These pins would selectively be turned on/off or kept on/off according to the proximity and direction of the obstacle. Actuators corresponding to these GPIO pins will hence convey the haptic information related to the location of the obstacle.

An object oriented programming approach was used to develop the logic in the software module for configuring the GPIOs. A GPIO class was created which contained methods to handle the interaction and functionality of the GPIO pins. Thus having an object oriented structure was important since it ensured that each GPIO pin was independent of the other pins. Following design logic was used in order to configure and set the GPIO pins:

```
// Instatiate GPIOClass object using the GPIO pin number
// Export the GPIO pin in order to set its value
// Set the direction of the GPIO pin (input or output)
// Set the value of the GPIO pin (turn it on or off)
// Unexport the GPIO pin to avoid accidental manipulation of its value

// Structure of the GPIOClass with its member functions

GPIOClass : :GPIOClass(string gnum) {
        this->gpionum = gnum;
}

int GPIOClass::export_gpio() {

        // Open the export file
        // Check whether the GPIO number is within a valid range
        // Export the gpio
        // Close the export file
}

int GPIOClass::unexport_gpio()  {

        // Open the export file
        // Check whether the GPIO number is within a valid range
        // Unexport the gpio
        // Close the export file

}
```

```
int GPIOClass::setdir_gpio(string dir) {

        // Open the direction file for the GPIO
        // Check whether we are allowed to set the direction
        // Set the direction of the GPIO pin
        // Close the direction file for the GPIO
}

int GPIOClass::setvalue_gpio(string dir) {

        // Open the value file for the GPIO
        // Check whether we are allowed to set the value
        // Set the value of the GPIO pin
        // Close the value file for the GPIO
}
```

3.1.4 Functionality to support interaction with the power module

Since the project is designed for the visually impaired, there is no visual way of letting the user know if the power and hence the ISEEU belt has been turned on. In order to convey this information an actuator has been placed on the belt, which is aligned along the back of the user. As the user turns on the power module, the microcontroller is turned on. The software module installed on the microcontroller then runs to generate GPIO signals for the actuator installed near the back of the user. The GPIO line is turned on and off repetitively, three times in total to help the user know that the system is now on.

3.2 Power Module

The Power Module is the heart of the ISEEU project. The power module is not only responsible for turning on the system but also providing power to all the components that make up the ISEEU system. It is portable for the user and self-sustainable for at least 2 hours.

3.2.1 Design Process

There were several items to consider when designing the power module:

1. Selection of the battery technology being used (Nickel Metal Hydride, Lithium Ion, Lithium Polymer, etc.)
2. Calculation of the operating voltage and amphour rating of the power supply
3. Selection of the power supply from the chosen technology of the battery
4. Casing of the power module and connections between the power module and the other components of the system (the microcontroller and the user control module)

First Step: Selection of the Battery Technology

The power module needed to be rechargeable to make it more user friendly and reliable. Three of the most common types of secondary battery (rechargeable) technologies were chosen and compared using criteria such as Nominal Voltage, Battery Life, Typical Cost and Energy Density as shown below in Table 4. The Nominal Voltage of the battery cell would help determine the amount of batteries needed to get the required output voltage. The Battery Recharge Life of a battery type tells how many times it can be recharged before it can no longer be used. Typical cost is very important not only for the end user but also for our prototype, as it should be cost effective. The most important criterion is the Energy Density which means how long the battery can last on its one charge cycle. The end product must be able to stay on for a certain amount of time to make the user satisfied and the product more reliable.

Table 4: Comparison of Different Battery Technologies [5][6]

Battery Technology	Nominal Voltage (V)	Battery Life (cycles)	Typical Cost ($/kWh)	Energy Density (Wh/kg)
Nickel Cadmium	1.2	1000	11.00	45
Nickel Metal Hydride	1.2	300-500	18.00	60-120
Lithium Ion	3.6	500-1000	24.00	150-190

From the table above, we came to the following conclusions.

- One, Nickel Cadmium has the highest number of recharge cycles allowed before the battery becomes obsolete (but this depends on the maintenance done).
- Lithium-ion has the highest Energy density but is also the most expensive. It also has the highest Nominal Voltage, so fewer amounts of batteries are needed.
- Nickel Metal Hydride provides a medium between the two since it is not as expensive as Lithium-ion but it has a higher charge Energy density.

While being cost effective, our team’s top priority was to make the power module last long during use as well as make the module as light as possible.
Keeping the above points in mind, we chose the Lithium-ion for the choice of battery technology.

The one potential safety hazard consideration was that the Lithium-ion batteries require some kind of protection. This could be because of overheating or discharging it below a certain level. This will be closely inspected during the verification phase when the ordered parts arrive.

Second Step: Selection of the operating voltage, amphour current rating and Power Supply

First Iteration

Listed in Table 5 below are the components which were chosen in the initial design of the ISEEU system, with their respective power consumption ratings. Based on these power ratings, a battery pack was chosen initially to meet with the power requirements of the system.

Table 5: Initial Projected Power Needs of ISEEU System [7][8][9]

Device	Operating Voltage (V)	Max Operating Current (mA)	Max Power Consumption (mW)	Max Power Consumption (W)
Panda Board	5	800	4000	4
Actuators for Haptic Feedback	2.05	630	1291.5	1.2915
3D Scanner Camera (Xtion)			2500	2.5
Projected Max. Power Consumption				**7.7915**

Table 5 takes into account the maximum voltage, current and power specifications of the components in the ISEEU system.

Second Iteration

Due to the change in the components used in the ISEEU system, the power requirements listed in Table 5 were revised. The new requirements are summarized in Table 6.

Table 6: Final Power Needs of ISEEU System [10][11][12]

Device	Operating Voltage (V)	Max Operating Current (mA)	Max Power Consumption (mW)	Max Power Consumption (W)
Microcontroller(UDOO board)	5	731	3,655	3.65
Actuators for Haptic Feedback	3	720	2,160	2.16
3D Scanner Camera (Xtion)			2,500	2.5
Projected Max. Power Consumption				**8.31**

Based on these power ratings, a battery pack was chosen initially to meet with the power requirements of the system. The total power requirement of the system was calculated based on the worst case scenario, when all components are consuming their rated power. This was done to ensure that a reliable battery pack is chosen.

Power Supply Logic Calculations

- The microcontroller requires an operating voltage of 5V. Since the power supply is directly connected to the microcontroller, it must supply a minimum of 5 V.
- The mAh rating of the supply can be decided by the maximum power consumption of the system.
- Since Power consumed should be equal to Power supplied, if we know the power required by the circuit, we can determine the power which needs to be supplied by the battery.
- Then based on the specified duration we can use E=Pt where P would be the power consumed and the required duration would replace the variable t.
- Finally, the amphour capacity of the battery can be found by solving It=E/V, using E, V values calculated from the previous steps.

Using the above points and Table 4, the final system requires a supply power of at least 8.31W. The Energy required for the battery to last for two hours is:

$$Erequired = Pconsumed * t$$
$$Erequired = 8.31W * 2hours$$
$$Erequired = 16.62Wh$$

Finally, to find the amphour rating we solve:

$$I * t = \frac{Erequired}{Vsupply}$$
$$= \frac{16.62Wh}{5V}$$
$$I * t = 3.324A \; or \; 3{,}324mAh$$

Therefore, the required power supply should be a 5V battery with at least a 3,324mAh capacity.

There were two approaches that were looked at for coming up with the operating voltage of 5V. The first design would involve perhaps using a 3.7V Lithium-ion battery pack and then using a Boost converter to step it up to 5V. There are many battery packs available with the 3.7V operating voltage, which have a wired connector output. Here the limitation happens with the inefficiencies of the boost converter connection. The second option was to buy a 5V DC regulated power supply that did not need the boost converter to satisfy the operating voltage and mAh specs. The downfall of this would be that there are almost no battery packs available with the required ratings with a wire connection as the output. Most of these packs have to be connected via USB to the device it is supporting. At the same time, this would eliminate the inefficiencies of a boost converter that we may pick. (i.e. It already comes with the required output voltage).

Ultimately, we decided to pick the second option, as there were many battery packs available with a USB output meeting the required ratings (5V operating, 3,324mAh). For the initial design that had required around 7.8W (Table 5), we had chosen PRT-11360 from Sparkfun Electronics. This Li-Po battery pack had a 5V DC regulated output and an amphour rating of 6,600mAh. After changing the microcontroller and actuators(iteration 2 in sections 3.3.4), the power requirements of the initial system had changed. The calculated power requirements of the final system is 8.31W (Table 6). For the final design, we have picked the Sailing 4 battery pack from Samsung's Romoss to meet the needs of this system. This 5V DC regulated pack outputs either 1 or 2.1A which is more than enough current for the system. It also has a amphour capacity of 10,400 mAh and a weight of 256g. This is 3,800 mAh more than the previous Sparkfun Electronics battery pack. The new battery pack also comes with built in over current and over voltage protections for a safe power supply. Hence, these ratings and safety precautions will allow not only the system but the power supply to run longer as well.

Connections with other modules

The power supply is a big part of the ISEEU system and is connected to both the user module and the microcontroller. The reason for the connection with the user module was to implement an on/off switch for the entire system. The user should be able to choose whether or not to turn the system on. The user module will basically act as an interface between the power supply and the microcontroller as shown in Figure 8 below:

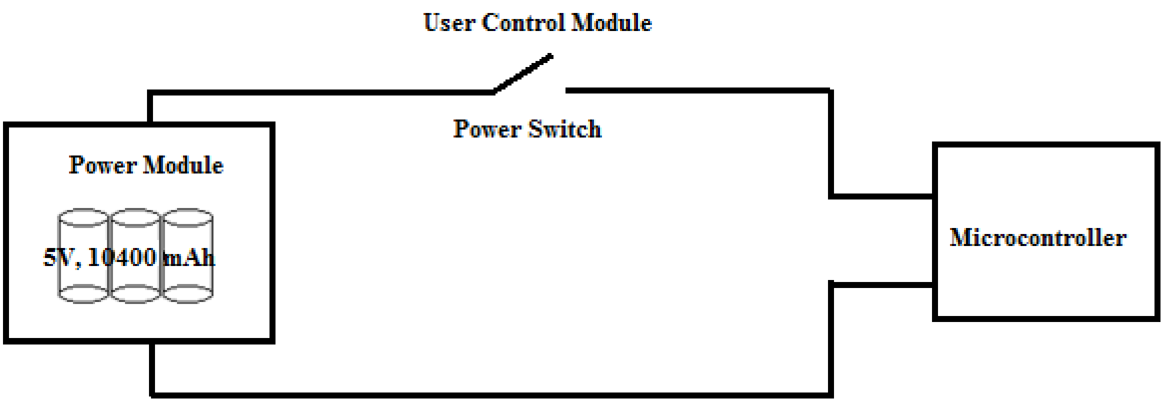


Figure 9: High level connection of power module connectors

Overall, the power module would have the following modifications and interconnections:

- One USB end of the power supply cable would have to be taken out of the casing and then should be connected to the switch of the user module.
- The wired output of the switch would then be converted to a barrel connection to the microcontroller.

It is important to note that throughout implementation, the design options mentioned above and the selected option are tested against each other to ensure the power module has the best design.

3.3 Haptic Feedback Module

3.3.1 Description

The Haptic feedback module is primarily designed to provide information to the user about their surrounding environment by stimulating their sense of touch. This module comprises of a mechanism that conveys the complex navigational information to the user in the form of vibrations, thus allowing the user to directly feel the directional and proximity information of the approaching objects. The vibrations are generated by using a total of 9 actuators installed on the ISEEU belt, which can be worn by the user along their waist.

As discussed earlier in the software module, in order to provide the directional information, the field of view of the user is divided into three regions: left, center and right. The actuators are divided into three sets consisting of three actuators each and these sets are then assigned to the three regions as shown in Figure 10. If an obstacle is detected within the left sector, the left set of actuators start vibrating to convey this information to the user. Similarly obstacles detected in the middle sector and in the right most sector cause vibrations in the middle and right set of actuators respectively.

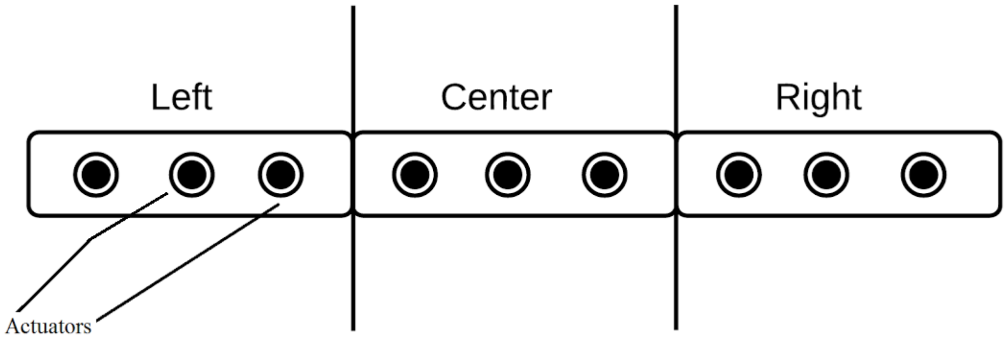


Figure 10: Layout of actuators on the ISEEU Belt

One of the aims of this module was to be able to convey information regarding the proximity of the obstacle. In order to achieve this, the intensity of vibrations is varied inversely with the distance of the obstacle from the user. The design iterations to achieve the same have been discussed below.

3.3.2 Design Logic to vary the Intensity of Vibrations

First Iteration

Originally it was planned that the operation of the actuators including the amplitude and frequency of vibration can be controlled by PWM (Pulse Width Modulation). This PWM was planned to be generated by the software module, which would do all the processing and would hence determine the corresponding voltage needed to drive the actuators in a particular situation. This information would then be conveyed to the microcontroller, which would then supply the required voltage to the actuators in the form of PWM signals. The basis of this design idea was that the driving voltage can be varied by varying the duty cycle of the PWM signal. This is because the input voltage of the actuators is directly proportional to the duty cycle of the PWM signal.

The circuit level design of the actuator connections for the first iteration is shown in the Figure 11. It was planned to connect three sets of actuators in parallel and three different PWM signals generated by the microcontroller would drive them. Another alternative was to connect the actuators in series but that was discarded because though a series connection leads to a lower overall current in the circuit, it requires a higher output voltage from the microcontroller (around 6.15V) which is higher than the maximum output voltage of the microcontroller).

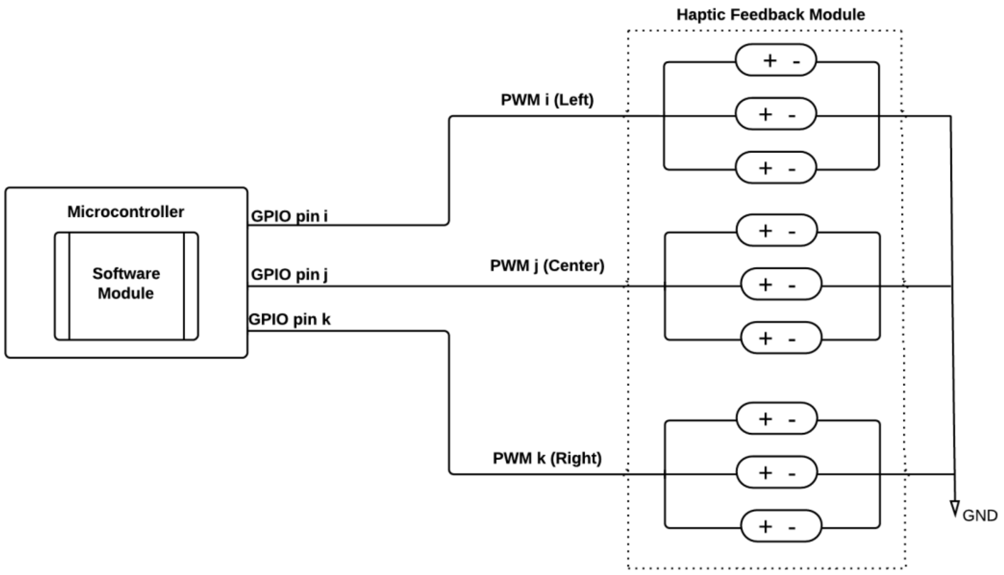


Figure 11: Haptic feedback circuit design

Second Iteration

The design of the first iteration was discarded due to the problems faced with the implementation of PWM, as discussed in detail in the software module. In order to support the concept of varying levels of vibrations in the new design, a new implementation was chosen. It was decided that it was also possible to convey varying levels of vibrations by varying the number of actuators vibrating at any given time. For example, in a particular direction (left, centre or right), if an object is detected in the far region only one actuator vibrates. As the object comes closer, into the middle region, the second actuator is turned on in addition to the first giving the user a feeling of increased vibrations. Similarly in the nearest region, all three actuators are turned on. This has been clearly summarized in Table7.

Table 7. The state of single set of actuators with varying proximities

Proximities	Actuator 1	Actuator 2	Actuator 3
Near (600mm < d < 1m)	ON	ON	ON
Middle (1m < d < 2.5m)	ON	ON	OFF
Far (2.5m < d < 4m)	ON	OFF	OFF

The circuit level design of the actuator connections for the this iteration is shown in the Figure 12. Since each actuator in this design is independent of other actuators and uniquely contributes to the functioning of this module, it made sense to drive each of the actuators using a separate GPIO signal. This also means that all the actuators will get the same 3V output GPIO voltage which would maintain good voltage distribution throughout the circuit.

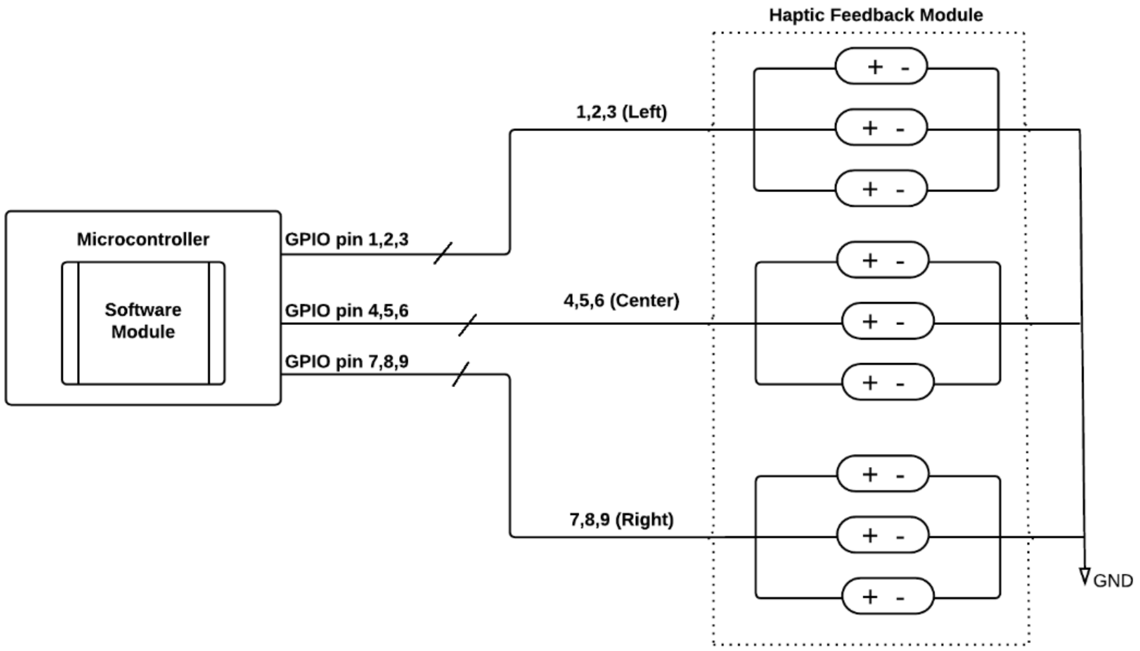


Figure 12: Haptic Feedback final circuit design

3.3.3 Technological Investigation for Haptic Feedback

Available Technologies

1. **Electromagnetic (EM) actuators:** While some EM actuators operate on the principle of actuators to generate vibrations, others generate vibrations due to the linear motion of a magnet and a mass along an axis. These actuators are lightweight, have low power consumption and are very easy to use.
2. **Piezo-Electric Devices:** The application of electric field can induce distortion in some types of crystals. This is the principle of operation of Piezo-electric vibrators. Recent Piezo devices are also small and lightweight. Moreover though Piezo-devices require far higher voltage than EM actuators, their extremely quick response rate results in a more power-efficient performance than the others [13].

3. **Electro-Tactile Devices:** This is the mechanism that involves the direct activation of the mechanoreceptors in the skin by passing a local electric current through the skin. These devices have low power consumption and they do not posses any mechanical parts (lightweight). However, the major problems can be skin irritations and even sudden pain caused in case the pain receptors in the skin are activated by the electric current [14].
4. **Pneumatic Systems:** This is the technique that allows the application of pressure (using pockets dynamically filled with air) in addition to the vibration to provide feedback to the user. However, due to high consumption of compressed air, pneumatic systems are not suitable for mobile use since they can make the device too bulky and uncomfortable for the user [15]. They also consume high energy and are too expensive.

Comparison and Analysis of above technologies

A weighted criteria matrix was used for analysis and determination of the technology to be used for the haptic feedback module. The actuator design having the maximum total score was selected to be the best suitable for our requirements. The evaluation criteria, with their assigned weights are listed in table 8 to make a final choice of the actuator devices to be used for the design.

Table 8: Criteria for evaluating Actuators for Haptic Feedback Design

Evaluation Criteria	Description and logical reasoning for determination of relative weight assigned to the criteria
Power Consumption	Since the power to the entire ISEEU system will be supplied by the battery packs, it was important to select the actuators that have low power consumption. However the power consumed by the actuators will be relatively low as compared to the other components on an average, therefore a weight of 6 was assigned to the power consumption criterion.
Weight	The actuators should be small and light weighted to ensure user comfort, since they will have to be carried around by the user throughout the day. This is important for user comfort and hence a weight of 8 was assigned to this criterion.
Noise Production	The noise produced by the actuators should be as low as possible. However latest actuators corresponding to all the technologies being compared produce little or no noise. Hence a weight of 7 was assigned to this criterion since little noise can be bearable and lower weight is more important as compared to lower noise.
Safety	There are some factors that cause a threat to the user's safety (high voltage, sudden pain) and since safety of the user is of utmost importance, a weight of 10 was assigned to this criterion.
Cost	The price of the actuators was also considered since the goal was to make the end product cost effective and affordable. However since this is not an essential criterion for our project, hence a weight of 5 was assigned to this criterion.

** Weight: 1 (least important) to 10 (most important)

For power consumption, cost, weight and noise production, a higher rating refers to a lower value of the corresponding criteria. However for safety higher rating implies the technology is safer for the user. The ratings assigned to the four technologies and the total scores obtained are shown in table 9.

Table 9: Weighted Criteria Matrix

Key Success Factors		Electromagnetic Actuators		Piezo-Electric Devices		Electro-Tactile devices		Pneumatic Systems	
	Weight	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
Power Consumption	**6**	4	24	5	30	4	24	2	12
Weight	**8**	4	32	4	32	5	40	1	8
Noise Production	**7**	4	24	5	35	5	35	5	35
Safety	**10**	4	40	2	20	1	10	1	10
Cost	**5**	5	25	2	10	1	5	1	5
Total Score			**145**		**127**		**114**		**70**

**Rating: 1 (low performance) to 5 (high performance)
***Score = Weight * Rating

Explanation of ratings assigned:

- Power consumption is low for Electromagnetic Actuators, however the Piezo Electric devices are even more power efficient as discussed before [13]. Electro-tactile devices also have low power consumption. Working of pneumatic systems is based on compressed air and hence these systems consume very high energy [16].
- Since electro tactile devices do not possess any mechanical parts, so they are the lightest in weight. Piezo devices and electromagnetic actuators are similar in weight. However, pneumatic systems are the heaviest of all.
- All technologies evaluated above, do not produce any noise, except Electro-magnetic devices (ERM actuators) produce noise due to the rotation of the actuators.
- Electro-tactile devices are not safe for the user since they can cause skin irritations and sudden pain to the user. Pneumatic systems involve application of pressure on the skin to provide feedback to the user and hence might not be safe for users with sensitive skin. Piezo-electric devices have high operating voltages (e.g. from 100V up to 1000V), which can be very dangerous for the user especially in case of circuit breakdown. EM actuators can produce heat due to rotation of actuators, which can cause problems if the actuators are in direct contact with the user's skin. However, latest electro-mechanical actuators designed for haptic feedback [17] do not produce heat and are safe to use for the purpose of our application.
- While electromagnetic actuators are very cost effective ($10 per actuator [17]), the Piezo-electric devices are a lot more expensive ($200 per device [18]). The average cost of electro tactile devices is around a few hundred dollars and the cost of operation of pneumatic systems is very high which is too high for this project.

Conclusion: Pneumatic systems as well as electro-tactile devices are inappropriate for long-term use, mainly because they are not user friendly. Compared to EM actuators Piezo-electric devices are not only relatively less safe to use, but also more expensive and hard to get. Therefore, EM actuators were finally chosen due to the highest score obtained by them.

Electromagnetic actuators

Form Factor:
Coin EM actuators were chosen over the cylindrical ones because they have a more compact form (as shown in Figure 13, are lighter and produce lesser or no noise as compared to their cylindrical counterparts. This will also make the physical arrangement and placement of coin actuators on the belt a lot easier. Moreover, coin actuators will be safer for the user, since the rotating part is enclosed inside the coin casing. The next step was to decide whether to use ERM or LRA coin actuators.

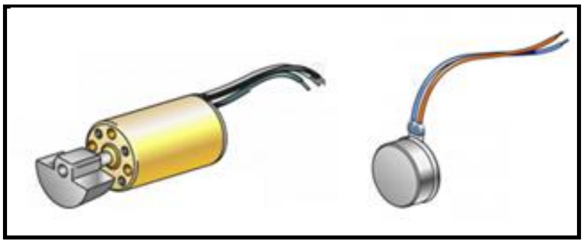


Figure 13: Cylindrical actuators (left) vs Coin actuator (right) [19]

ERM Vs LRA:

- **ERM (Eccentric Rotating Mass) vibration actuators:** These actuators consist of a rotating mass fixed at the end of the rotor, which on rotation throws the actuator out of balance causing it to shake. These actuators require a DC voltage to operate. This can be achieved by generating a PWM signal of a fixed duty cycle within each cycle.
- **LRA (Linear Resonant Actuator) vibration actuators:** In an LRA, a magnetic field is generated by the current flowing through a voice coil, which interacts with a magnet & mass, suspended on a spring. As the magnetic field varies with the applied drive signal, the magnet & mass are moved up and down linearly as they interact with the spring. These actuators require an AC input signal for operation. We can generate varying the duty cycle of the PWM signal in each cycle can generate this AC signal.

3.3.4 Final Choice of Actuators

First Iteration
We had initially decided to use a linear resonant actuator for our project due to the following reasons:

- LRA's typically offer improved haptic performance with short lag and rise times [17].
- They consume lower power than their ERM equivalents.
- The input signal's amplitude and frequency are independent of each other as opposed to ERM actuators whose frequency is directly proportional to the amplitude of

vibration. This means that when the input voltage is increased, the amplitude of vibrations will increase without affecting the resonant frequency. Thus, this allows for auto resonance and can provide higher vibration strength and a better haptic experience to the user.

Second Iteration

With the change in the design of the "proximity" implementation as discussed in section 3.3.2, the points mentioned above were discarded on the following basis.

- On practically comparing the actuator performance, it was found that the difference between the lag and rise times (time for the actuator to start vibrating after the GPIO signal is received) of the LRA and ERM actuators was unnoticeable.
- The final battery selected for the project was able to provide ample amount of power (amphour capacity of 3,800 mAh), such that the constraint to consume minimal power was no longer a limiting concern. This is as evident from the calculations presented in the power module. Thus ERM and LRA stood equivalent from this respect.
- Since the input voltage provided to the actuators is no longer being increased and is a constant, this argument is no longer valid in the light of the new design.

Since ERM and LRA actuators stood out to be equivalent in the new analysis, the cost of the actuators was chosen as the deciding factor. The LRA actuators chosen for this project cost $10/actuator and the of ERM actuators cost $25/10 actuators. Thus ERM actuators from the manufacturer SolarBotics (model number: 2645-CA1) were chosen for the final design.

3.4 User Control Module

3.4.1 Description

The User Control Module is designed so that users can control many aspects of the ISEEU system. It includes a power switch and can potentially include an intensity control switch. This module focuses on the selection of electrical switches based on the system's applications. The user's interface with the system is an important factor in our design and plays an important role in the ease of use of our product.

Switches are of different types, of different specifications and are selected and used in a particular application according to specific requirements [20]. There are mainly three classifications of switches: manual switches, detection switches and setting switches. For the purpose of our project, manual switches are used. There are many ways to categorize switches; one way to categorize a switch is by how the user is opening or closing the switch contacts. This category is chosen to determine the type of switch in order to make sure that the user can easily tell the state of the system by sense of touch.

3.4.2 Power Switch

The Power switch is a very simple non-momentary two states (on and off) switch. The switch makes or breaks the contacts between the DC power supply and the microcontroller in order to control the whole system. It is designed to make sure that once the switch is closed, it must have a low resistance and a stable power transfer.

When selecting the switch, the following specifications were considered:

- The power supply rating is 5V, 6600mAH. (based on the first iteration in section 3.2.1 of the power module)
- Pole and Throw: SPST (single pole single throw)
- Contact Rating: 5V, 2 A

There are three types of switches that we considered: Toggle switches, Rocker switches, Push Button switches. Following are the iterations performed for this module.

<u>Iteration 1</u>

Initially, we thought that the toggle switches and rocker switches can be switched on and off by accident. Since there is no additional supervision of the power switch position, the power switch state should be intentionally changed by the user. Therefore, a non-momentary Push Button type switch was selected for the design.

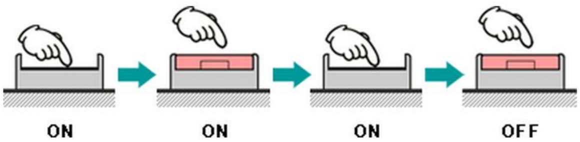


Figure 14: Non-momentary Push Button switch

Figure 14 shows the mechanism of the power switch selected in the first iteration. When the user pushes the button, it will stay on after the push is realized. When the user pushes it again to break the connection, it will stay on until the push button is released. This mechanism was designed to make the power transfer stable when connected.

Intensity Switch

In the first iteration, we had planned to implement an intensity regulator. The purpose of this intensity regulator was to provide the user an option to select the range of intensities felt on the detection of the objects in the surrounding environment. This was done to ensure that the user was comfortable with the level of intensities experienced while using the ISEEU system. The Intensity switch for the regulator was designed to notify the microcontroller about the intensity range selected. Figure 15 a) shows how the selected intensity level was distributed into three different vibration frequencies of the actuators for haptic feedback. As shown in Figure 15b), the intensity switch would get connected to either microcontroller input 1, 2 or 3 based on the user's choice of intensity. Then the software module would process the signal accordingly to generate PWM outputs sent by the microcontroller to the actuators in the haptic feedback module. This is explained in detail in iteration1 of section 3.1.3 of the software module where the interaction of haptic feedback module with the software module has been explained.

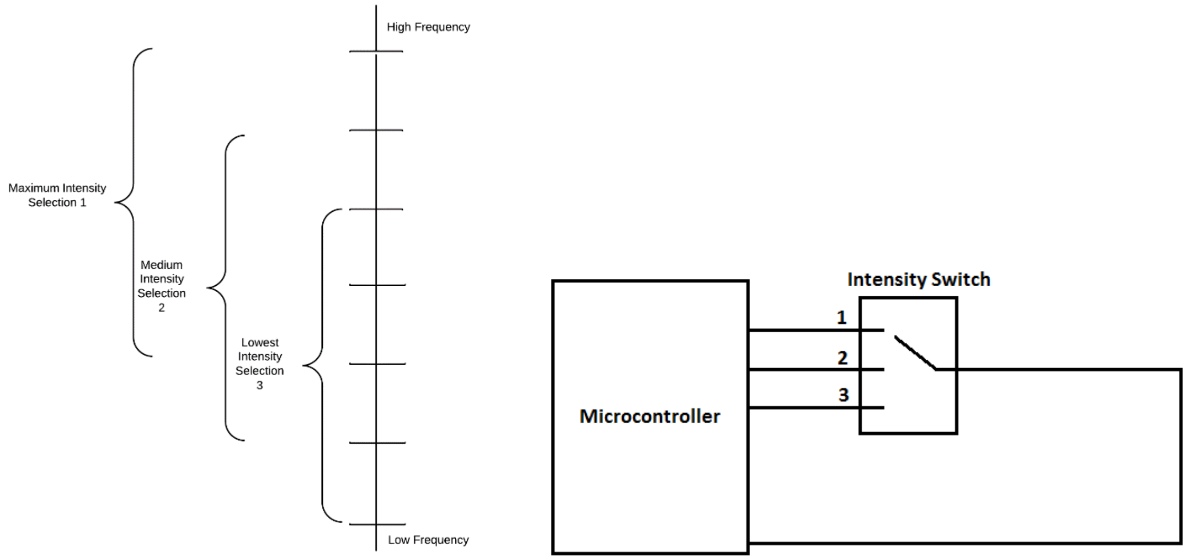


Figure 15: a) Intensity level diagram b) Intensity switch

A rocker type switch was selected for the design of the intensity regulator switch, because a push button cannot be used for the triple throw mechanism (shown in Figure 15b) needed for this implementation. Rocker switch is also more reliable as compared to a toggle switch.

When selecting the rocker switch, the following specifications were considered:

- Pole and Throw: SPTT (single pole triple throw)
- Contact Rating: 5V, 2A
- Actuator type: Rocker

Iteration 2

After testing our implementation of the Push Button switch in the first iteration, we realized that there was a major problem with using it for our design. The purpose of having the switch was not only to give the user control over the system but also to make sure that the user is aware of the current state of the system (i.e whether the system in ON or OFF). On testing with the push button, we realized that it would be very difficult for a visually impaired person to figure out what state the system was in, if a push button is used. This is because it is difficult to differentiate between the on and off states of the push button by simply touching/feeling the push button. Therefore a Rocker switch was selected to replace the push button since it relates the state information with the direction (Example: switch when pressed on the left would indicate the on state and when pressed on the right would indicate the off state). Also in order to avoid the switch from turning on or off by accident, we chose a switch which required considerable amount of force to be turned on. Moreover, it was also evaluated that it would be better to use a rocker switch over a toggle switch since a toggle switch has its' switch stick protruding out due to which it is easier to accidentally turn it on and off. Therefore, a Rocker type switch was selected for our final design of the power switch.

Figure 16: SPST Rocker Switch [21]

Figure 16 shows the power switch which we chose. The operating mechanism of the switch is that when the user flips the switch from off to on, connection is made and when the user flips it back, it will break the connection right away. This type of switch can ensure that the power transfer is stable when connected.

Following are the final specifications of the switch which was selected:

- Voltage Rating = 125V AC
- Current Rating = 5A AC
- Pole and Throw: SPST (single pole single throw)
- Actuator type: Rocker

Intensity Switch

In this iteration we decided to eliminate the intensity Switch from our project due to the problems faced with the implementation of PWM, as discussed in detail in the software module. However, this can be considered as something which can be improved and incorporated into the project design in the future.

4. Prototype Data

This section presents data to justify that our specifications for this project are being met.

4.1) Battery life should be at least 2 hours

The design finalized for the battery consists of a battery pack with a rating of 10.4 Amphour. The maximum current that our system can draw if all components work at their full capability is 2A. Thus for the chosen battery, the battery will last for the following amount of time for our system:

10.4 Amphour/2 Amp = 5.2 hours

Thus clearly the power module meets the essential specification even when operating at its full rating.

Moreover, besides the battery life, the power module also supplies enough power to meet the power requirements of the entire ISEEU system. This has been discussed in detail in the power module (Section 3.2). Table 6 in that section shows the power requirements of different components of the ISEEU system

Figure 17 shows the how the power supply is connected to the microcontroller through a rocker switch.

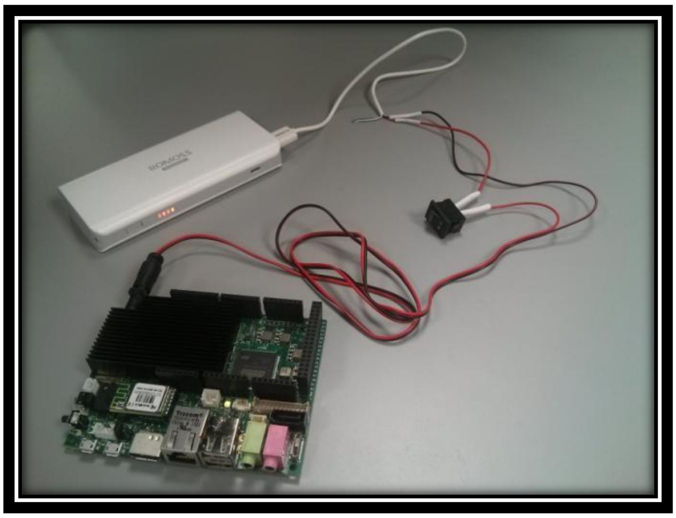


Figure 17. Battery connection with the microcontroller through the switch

4.2) Three levels of intensity of the vibrations for haptic feedback

The ISEEU system is designed to convey the proximity information to the user based on the distance of the object from the user. We have used LEDs instead of actuators to depict this, as it is difficult to visually depict actuators vibrating. The three images in Figure18 shows the following:

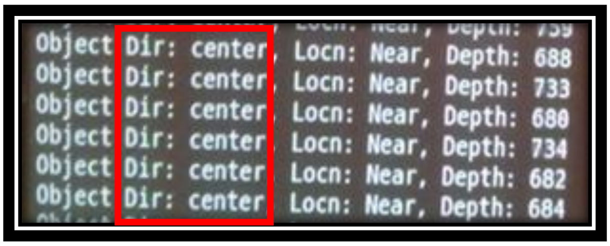
- When the user is in the far region (2.5m < d < 4m) - Only one LED is lit (left image)
- When the user is in the far region (1m < d < 2.5m) - Two LEDs are lit (centre image)
- When the user is in the far region (400mm < d < 1m) - Three LEDs is lit (right image)

Figure 18. Depiction of different levels of intensity based on proximity

4.3) Detection of objects on left, center and right of the user's front view

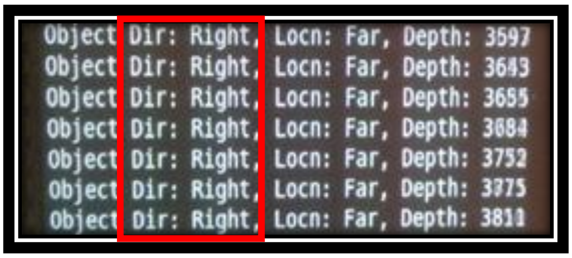
In order to prove that our system conveys directional information about the location of objects to the users, we have used print statements at the locations where the software would be sending GPIO signals to the actuators in the three directions (left, center, right).

- Object is located in the centre of the user's front view, in the near region



- Object is located in the left of the user's front view, in the middle region

- Object is located in the right of the user's front view, in the far region



4.4) System supports three actuators in each direction for object detection

Figure 19 shows the placement of three actuators in each direction on the ISEEU belt. Each actuator is important since each one of them has a specific role in determining the region and direction of the object in the surrounding environment of the user

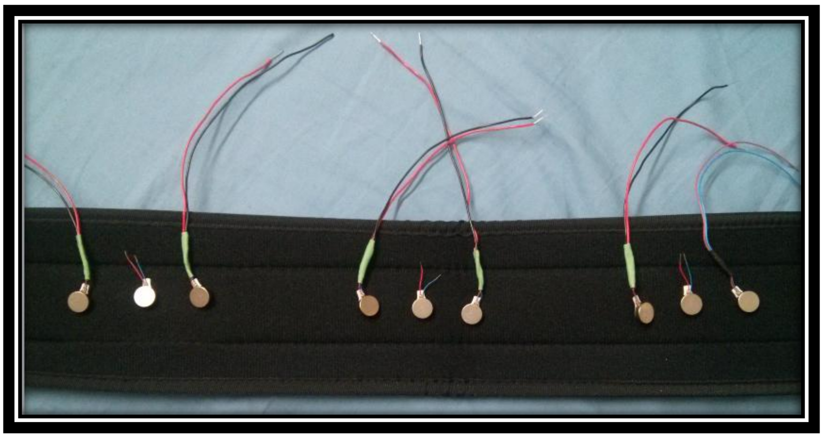


Figure 19. Placement of three actuators in each direction on the ISEEU belt

The signals from the microcontroller would be conveyed to the actuators through the GPIO pins. Figure 20 shows the GPIO response of one such GPIO pin.

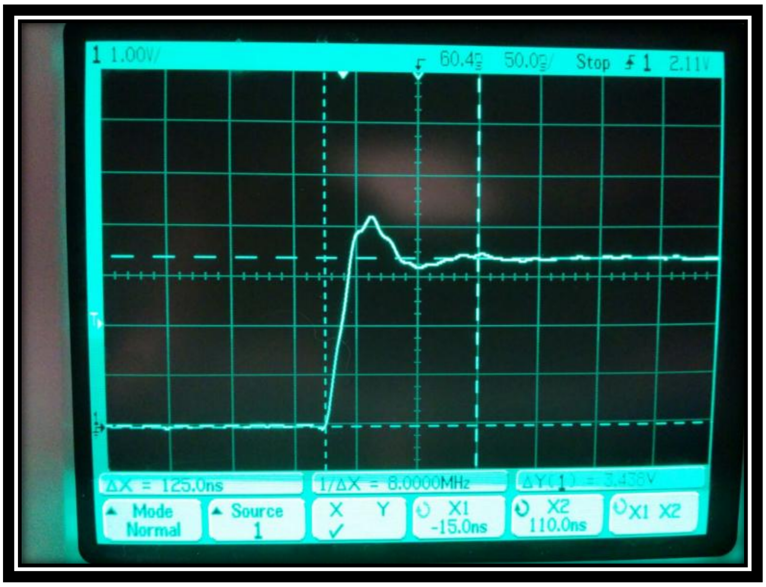


Figure 20. GPIO response

4.5) Weight and Cost of the System

The Table 10 shows the breakdown of the the cost and weight of different components in the ISEEU system. The total weight 454.5 g is less than the maximum weight of 1kg and the total cost $540 is less than contstrain price of $700 which satisfies our specifications.

Table 10. Component price and weight listing

	Weight	Cost
Microcontroller (UDOO)	39.7 g	$135
Power Supply (Samsung ROMOS)	256 g	$30
3D Scanner Camera (Asus Xtion)	50.5 g	$250
Belt (Valeo)	20 g	$40
Casing for UDOO	50.8 g	$30
Actuators	19.7 g	$25
Wires, Switch, heat shrink etc.	18 g	$30
Total =>	454.5 g	$ 540

5. Discussion and Conclusions

5.1 Evaluation of Final Design

The original specifications are listed in the table below:

Table 11. Evaluation of project specifications

No	Specifications	*E/NE	Satisfied?	Subsystem
1	Battery life should be at least 2 hours	E	Yes	Power
2	The intensity of the vibrations for the haptic feedback should vary with the range of distance of the object from the user on a scale of at least 3 - Low (600mm < d <1m), Medium (1m < d < 2.5m), High (2.5m < d < 4m)	E	Yes	Software
3	System should be able to differentiate between objects located on left, center and right of the user's front view	E	Yes	Software
4	System should support at least 3 actuators in each direction for object detection in that direction.	E	Yes	Haptic Feedback
5	The user should be able to choose between three different ranges of intensity	NE	No	User -Control
6	Weight of the system should be less than 1kg	NE	Yes	ISEEU Belt
7	The cost of the end product should not exceed $700	NE	Yes	ISEEU Belt

<u>**Power Module**</u>:
The design finalized for the battery consists of a battery pack with a rating of 10.4 Amphour. The maximum current that our system can draw if all components work at their full capability is 2A. Thus for the chosen battery, the battery will last for the following amount of time for our system:

$$10.4 \text{ Amphour}/2 \text{ Amp} = 5.2 \text{ hours}$$

Thus clearly the power module meets the essential specification even when operating at its full rating.

Software Module:
The software module has been designed in a way that it meets with both the specifications, 2 and 3. The details of the design as mentioned in the Software Module, clearly indicate how these specifications are met with.

Haptic Feedback module:
One of the objectives of choosing three actuators in each direction was to ensure that the system is able to convey the proximity information to the user. This objective is clearly met and is discussed in detail in the haptic feedback module

User-Control Module:
The intensity level switch on the user control module was a very challenging aspect of our project. This was because of the fact that our project already produces 3 different intensities of vibrations corresponding to the proximity of the obstacle from the user. Allowing the user to further select the intensity according to their comfort would result in 3*3 = 9 levels of vibration intensities to be configured on the actuator performance characteristic curve. This turned out to be challenging due to the problems faced in the implementation of PWM as discussed in the software module. Moreover, on testing with the selected actuators it was found that all the 9 intensity levels were not clearly distinguishable by the user. Thus, the intensity regulator was discarded from our project design, and will be considered for future extension of the project.

Weight and cost of the system:
The weight of the system was initially proposed to be less than 1kg. After the design iterations we made changes to the following components to be used:

- Power supply
- Weight of wires and connectors needed to connect to the system
- Microcontroller

However the total weight of the system which is 454.5g as shown in table 10 is well within our specified limit.

The initial cost of the system was estimated to be $700. However, during the design iterations, several changes were made to various components including the choice of the microcontroller, the actuators, the barrel connectors and the battery chosen for the power supply. However, the total cost of the system came out to be $540 as shown in table 10, which is still within the specified limit of $700.

5.2 Use of Advanced Knowledge

Upper year engineering knowledge used in this project:

- ECE 250 (Algorithms and Data structures) and ECE 457A: (Co-operative and adaptive Algorithms):

The knowledge of dynamic algorithms and data structures as well as image processing was used extensively in the design analysis of software module. Moreover genetic algorithms were used in our final design of the software module.

- ECE 224 (Embedded Microprocessor systems) and ECE 429 (Computer Architecture):
  The knowledge from these courses was used to decide the microcontroller to be used in the project. It also helped to understand the behavior of interaction between the microcontrollers with the other modules. The knowledge, and pros & cons of interrupts vs. polling helped us immensely in making some major interfacing design decisions.
- ECE 463 (Design and application of Power Electronic converters)
  The knowledge of PWM and actuator drives was used during the iterations for the design of the Power Module and the Haptic Feedback Module.
- MSCI 331 (Optimization and operations research)
  This course helped us to optimize our design objectives while meeting with various design constraints (specifications).

5.3 Creativity, Novelty and Elegance

In our opinion the elegance of the project lies in the fact that the whole system comes together into one single elegant, portable and user-friendly belt, which can be comfortably worn around the waist.
It is also novel since we are implementing three different levels of actuator intensities to convey the proximity information to the user to make them independent.

One of the ways our design is creative is because we are adding an intermediate terminal between the microcontroller and the actuators in the haptic feedback module. Jumpers are used to convey the signals coming from the GPIOs in the microcontroller to the terminal which then sends them to the actuators as shown in Figure 21. This ensures the safely of our design and also prevents the connections between the microcontroller and the actuators from breaking.

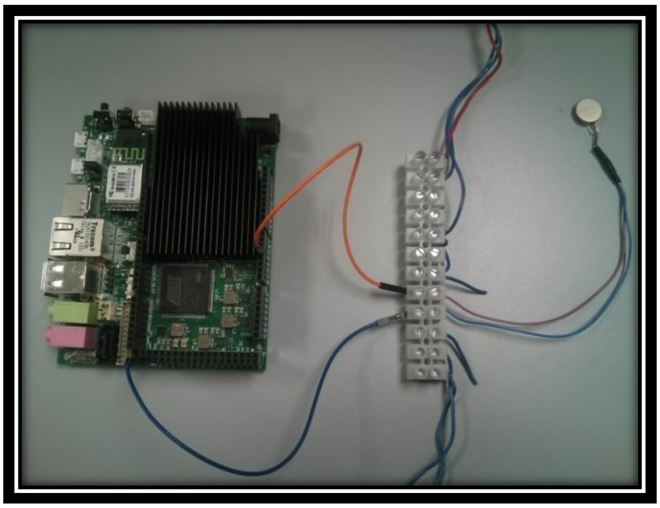


Figure 21. Using an intermediate terminal platform for routing connections

Our design is also elegant due to the fact that we made a startup script which automatically turns the entire system on when the microcontroller is turned on by the user through the switch in the user control module. Thus there is no extra effort needed to separately turn on different components in the ISEEU system.

Another important aspect of the design which makes it elegant is the use of Adaptive algorithms and parallel programming as explained in detail in the software module.

5.4 Quality of Risk Assessment

Table12 lists that risks that were assessed in the beginning of project and also states how effectively each of them were mitigated during the development of the ISEEU system.

Table 12. Risk Assessment and mitigation

Nature: Group dynamics **Situation:** Schedule mismatch in 4B (winter 2014)	**Impact :** The teamwork and collaboration will not be as frequent and effective. **Severity :** Medium **Probability:** Medium **Mitigation:** As predicted, all four group members have different schedules since we are enrolled in different courses. However, we are able to successfully mitigate this risk by setting weekly meeting times to work on the design project. Furthermore, we also shared our schedules with each other and created a group chat so that we could coordinate effectively and inform each other in case of any changes in the meeting times.
Nature: Group dynamics	**Impact :** There are two possible impacts if this situation occurs: • First, we fall short of team members since we are a group of 4.

Situation: One of the team members doesn't make it to 4B	• Secondly, since we have planned our project in a way that each person is responsible for a specific area, this will result in a loss of technical expertise in that area. This will result in extra time being spent by the team to research and gain knowledge in that particular area. **Severity :** High **Probability:** Low
	Mitigation: Fortunately, all the group members made it through the 4A term, though we planned for the worst case and mitigated this risk by communicating updates made in the design of each module in the ISEEU system. Example: we made sure that we commented all the code properly in the software module. Further, we ensured that at least two group members worked on each module
Nature: Insufficient knowledge and skill set **Situation:** Team members have taken the following courses expecting to earn the project related skills: i) Powerconverters ii) Adaptive algorithms (Image Processing) There is a risk is that courses would not cover the specific expected skill set.	**Impact :** We will have to acquire the deficit knowledge and skills through other resources which will take additional time and efforts. The resulting learning curve for the team will be steep and will result in delays in the project implementation. **Severity :** High **Probability:** Medium
	Mitigation: We talked to the course professors early in the term to figure out what all topics would be covered in the courses we took. This allowed us to plan early and enroll in the online courses to learn the concepts which would not be covered in the courses we took. We also spent time learning these concepts during our coop term which helped us to reduce the steepness of the learning curve in the 4B term. One thing that did go wrong was concerning the original microcontroller we chose (PandaBoard). Even after following the instructions for installing the OS on the board, the board would not boot up as expected. After spending a lot of time debugging (using our knowledge and online sources), we could still not find a solution to this problem. This was the main reason why we decided to switch to a different microcontroller (UDOO). Perhaps knowing more about the board and OS design would have helped us with this situation.
Nature: Technical risk **Situation:** If something blocks the Xtion camera, specially the user's own body part, accessory or clothes.	**Impact :** Anything closer than 80cm is detected as a big black dot by the Xtion camera, which will result in failure of the design. **Severity :** High **Probability:** High
	Mitigation: To discuss this issue, we arranged a meeting with our consultant during the earlier phase of the project and decided to avoid this issue by training the users on how to avoid this risk. Basically the user would be made aware of the fact that something too close to them (at their arms length) would not cause any vibrations and that they should used their arms/hands in order to reach for anything in their extremely close proximity.

From the discussion in table4 it can be seen that the risks were well assessed in the beginning of the project in terms of the severity and probability of occurrence. The list proved to be an exhaustive list and there were no other risks found in the course of project development. However, as the project progressed, we continued to come up with new ways to mitigate the existing risks.

5.5 Student Workload

The workload for the project was almost equally distributed among the team members (25% each). Most of the work was carried out in parallel usually by working in groups of two. This ensured that at least two team members had knowledge about the implementation of each part of the system.

Hours put in so far by each team member during the 4A and 4B terms:

- Michelle: 160 hours
- Jenny: 172 hours
- Sugandha: 164 hours
- Khushi: 170 hours

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Appendix A

ECE498B: Prototype Hazard Disclosure Form* Group number: 2015.016		
Instructions: Answer all the following questions by putting an *X* in either the yes or no column. If unsure, answer yes. If you answer yes to any question, set up an appointment with the Lab Instructor to ensure your prototype is safe for the symposium. Include this completed form in your Final Report (Appendix A) even if you answer no to all questions.		
Question: Does your prototype…	**yes**	**no**
1. include any circuitry that you designed or built by yourself?	X	
2. include any circuitry that is not enclosed in an approved plastic or metal electrical box?	X	
3. involve any 120V AC circuitry/device that is not approved by CSA or ESA?		X
4. involve circuitry that is not connected to its power supply with a fuse and a switch?	X	
5. use high-capacity or high-density (e.g., lithium-ion) batteries?	X	
6. emit non-trivial amounts of RF radiation?		X
7. involve x-rays or radioactive materials?		X
8. use unprotected lasers of any class?		X
9. involve strobe lights?		X
10. have exposed moving parts that may pinch, hit, or crush a person?		X
11. involve projectiles or any part that can fly?		X
12. have exposed sharp edges or points?		X
13. use high-pressure gases or liquids?		X
14. involve irritating or dangerous chemicals (assume all nano-materials are dangerous)?		X
15. involve any biological materials (dead or alive) or any food/drink?		X
16. emit dangerously loud sounds?		X
17. eject gas, particles, or fluids into the environment?		X
18. involve accessible components that reach temperatures above 40^{o}C or below 0^{o}C?		X
19. involve any other hazard? Describe:		X

Appendix B

ECE498B: Symposium Floor Plan Request Form* Group number: 2015.016			
Question:	**yes**	**no**	**if you answered "yes"…**
1. Does your project require one or more hardwire internet connections at the symposium? **Note:** We provide Ethernet connections only, via a male RJ-45 connector. The connection comprises a static IP address in the uwaterloo.ca domain on a shared 100Mbps link. Do not count on the DC building wireless system being available for your project.		X	If yes, state how many connections you require:
2. Do you desire to use your own wireless router at the symposium? If yes, you will need to have your setup approved well before the symposium date. Unapproved routers are strictly prohibited.		X	If yes, contact Paul Ludwig for details as soon as possible.
3. Each booth has a 7.5-amp 6-outlet power bar. Does your project require more than 7.5 amps of mains (120 V AC) power?		X	If yes, state how many amps you require in total:
4. Each booth has a 7.5-amp 6-outlet power bar. Does your project require more than 6 outlets?		X	If yes, we will supply your booth with two power bars.
5. Do you intend to put any electronics/computers on the floor under your booth?	X		If yes, we will ensure you can do this safely.
6. Does your project involve projectiles or flying parts? (We have a large "cage" at the symposium for projects that involve projectiles or flying parts.)		X	If yes, state the nature of the projectile or flying part:
7. Does your project require special lighting conditions (e.g., dim light, bright light)? We will do our best to accommodate lighting requests, but no guarantees are made.		X	If yes, state the nature of the desired lighting conditions:
8. The default booth consists of a 5' wide by 2.5' deep table. The table is 2.54' tall. Does your project require extra table space (giving you a total table area of 7.5' wide by 2.5' deep)? We will do our best to accommodate space requests, subject to the urgency of the request and overall space and safety constraints.		X	If yes, explain specifically why you are requesting the extra table space:
9. The default floor space, including the table and area for you/visitors to stand, is around 6' by 6'. Does your project require extra floor space? We will do our best to accommodate space requests, subject to the urgency of the request and overall space and safety constraints. **Note:** Due to the extra-large class size this year, very few requests for extra floor space will be granted.	X		If yes, explain why you need the extra floor space: * (see below) State how much extra space you are requesting: **5m x 2m**
10. Do you have any other special floor plan requests?	X		State your request: ** (see below)

*Extra floor space is needed since our project involves object detection over a range of 4m distance from the user. Therefore, in order to demo the essential specifications, we will need floor space of 5m x 2m.
**Prof. Ludwig suggested us to create a boundary around the demo area using cones and coloured tape. We will also need at least three stools which will act as obstacles during the demo.

Appendix C

Figure 20 shows the some of the motors investigated during the iterations of the haptic feedback module.

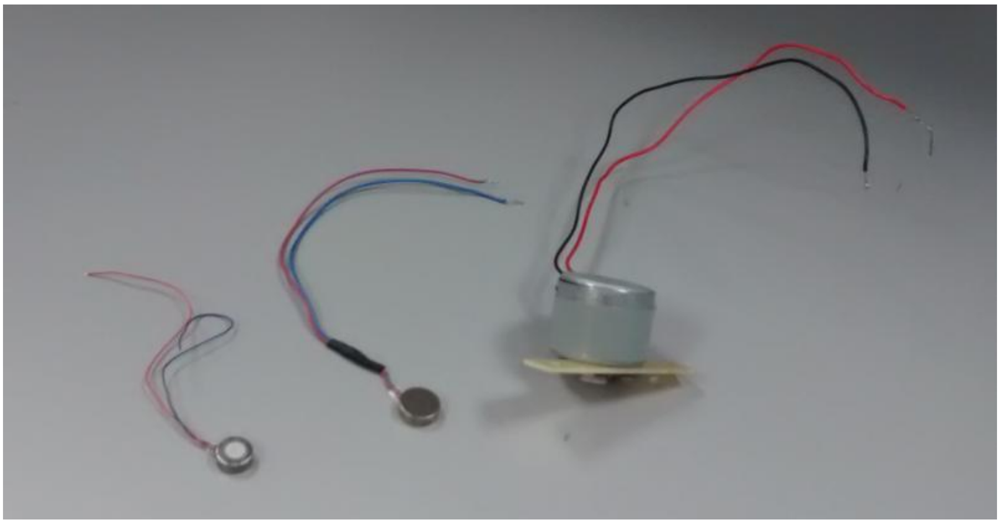

Figure 22. Various types of actuators considered

Figure 21 shows the cable which we created during one of the iterations of the power module. The cable was designed to connect the battery directly to the microcontroller without any intermediate switch.

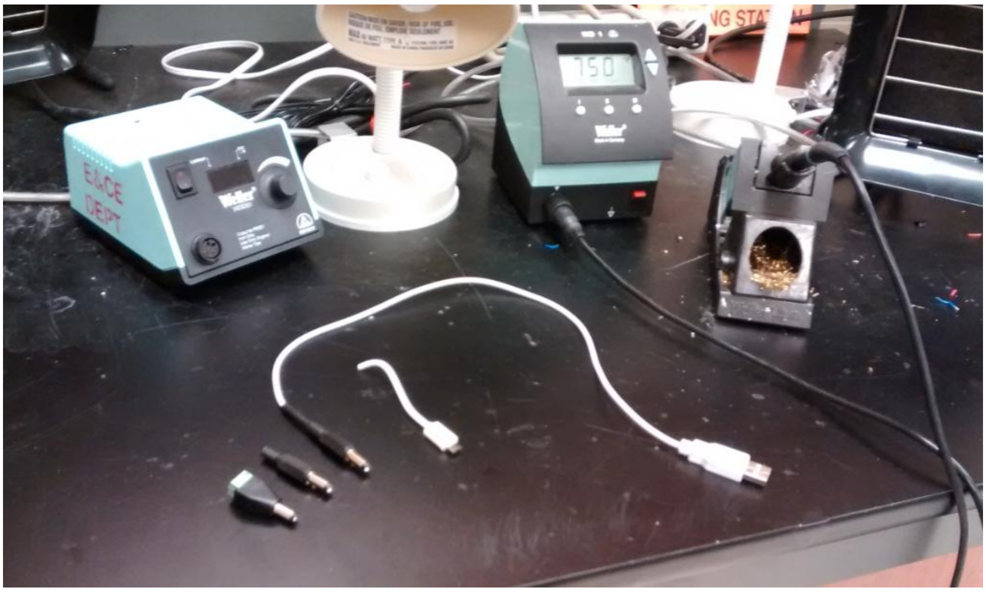

Figure 23. Cable implemented for connecting the battery to the microcontroller