2/28/2019

EML4551-2

Team 513: Virtual Reality Tracking and Realistic Haptic Feedback Gloves

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Abstract

The goal of our project is to make a pair of gloves for Lockheed Martin that allow for the user to train in a virtual reality Abrams tank. Active training units are large and costly, so using virtual reality lessens the cost and size of the training space. The gloves are usable with the Unity virtual reality game engine and HTC Vive virtual reality unit. The Vive unit consists of a headset to view the virtual world, and sensor boxes to track where the headset is. The gloves are easy to use, washable and allow for use with physical controls. The gloves are also strong and comfortable. The overall design has two main units. These units are tracking the gloves, and the response given by the gloves. To achieve the tracking a series of sensors find the hands. This moves through a Vive tracker to the computer to create a copy of the user's hands in the virtual world. The response unit lets the user know when they touch an object in the virtual space. The response is the result of motors placed on the fingers and palm of the hand. These motors vibrate when the user touches a virtual object to mimic the user's sense of touch. This vibration lets them know they have touched something in the virtual space. This response allows the user to work with virtual controls from the sense of touch. The motors and sensors are placed on the gloves to not interfere with their touch. This lets the user work with real world controls and virtual controls at the same time. The gloves easily move from person to person to limit down time between switching to a new trainee.

Chapter One: EML 4551C

1.1 Project Scope

The project description asks the team to design a pair of haptic feedback gloves to provide sensations like those derived from actions such as pushing buttons, flipping switches, and turning knobs in a virtual reality environment. The key goals for this project are to make the gloves portable, lightweight, and durable. The gloves will have full mobility and will provide haptic feedback for the palms of both hands and all ten fingers. The primary market of this project is the aerospace and defense company, Lockheed Martin, who requested this system to be used for their training simulators.

1.2 Customer Needs

To develop the customer needs, the team created a series of questions to develop an idea of the project outcome. After developing the questions, a teleconference was held between the team and our Lockheed Martin sponsor, Jeff Payne. Based on the customer statements, our interpreted needs were developed. Each customer statement was turned into an interpreted need that is unambiguous, verifiable, and traceable. Table 1 below shows the interaction between the customer and the team as well as the developed interpreted needs.

Table 1
Customer Interaction

QUESTIONS	CUSTOMER STATEMENTS	INTERPRETED NEED
Does it matter what kind of gloves we use for our design?	We want a pair of gloves, flexible with full mobility	One pair of gloves that are lightweight
What is the main use for the gloves?	Military training exercises	Transferable from one person to the next
Do the gloves need to be cleaned or sanitized often?	Cleaned after each training session	Regular cleaning after each use
How many things need to be tracked i.e. tracking just the hand, the hand and 3 fingers or the hand and all fingers?	Both hands and fingers to simulate real world training	Full hand and finger tracking in real-time
How in depth are we trying to make haptic feedback? (i.e. Being able to feel different materials or shapes, just vibrations to alert user they're in contact with an object, etc.)	Indicate to the user that something has happened	Provide basic haptic feedback for each finger and palm
Will the user be intersecting with only the virtual environment	No, physical joysticks and other objects will be included in the training sessions	Tactile feedback to be retained while still providing haptic feedback
Are there any limitations to the power source for the gloves?	There should be no connections limiting the training session	No wires restricting the user's range of motion
Is there a preferred software for the virtual environment?	We use Unity	Unity software engine used to develop virtual environment
Can we use any VR headset?	An HTC Vive will be provided	The overall design to be compatible with the HTC Vive

Using the customer statements and project scope, our team determined the most significant needs to be one pair of gloves that are lightweight, full hand and finger tracking in real-time, and providing basic haptic feedback for each finger and palm. The compatibility of the overall design with the HTC Vive VR system and Unity software engine are significant constraints. This is due to Lockheed Martin currently using the HTC Vive and Unity engine in their training. It is beneficial for our design to consist of a pair of gloves to interact in the training session. Without a full pair of gloves, the training will not be realistic. For the user in the training session to interact with the virtual environment in a realistic manner, full hand and finger tracking in real-time is needed. Without accurate and quick tracking of the hands, the user will not be able to train effectively. To further provide Lockheed Martin with realistic training, haptic feedback is necessary. This is what allows the user to interact with the virtual environment, and still get a level of realistic feedback. Using the virtual environment with full hand tracking and haptic feedback, Lockheed Martin is able to provide a realistic training scenario while reducing the size and cost of the required equipment.

1.3 Functional Decomposition

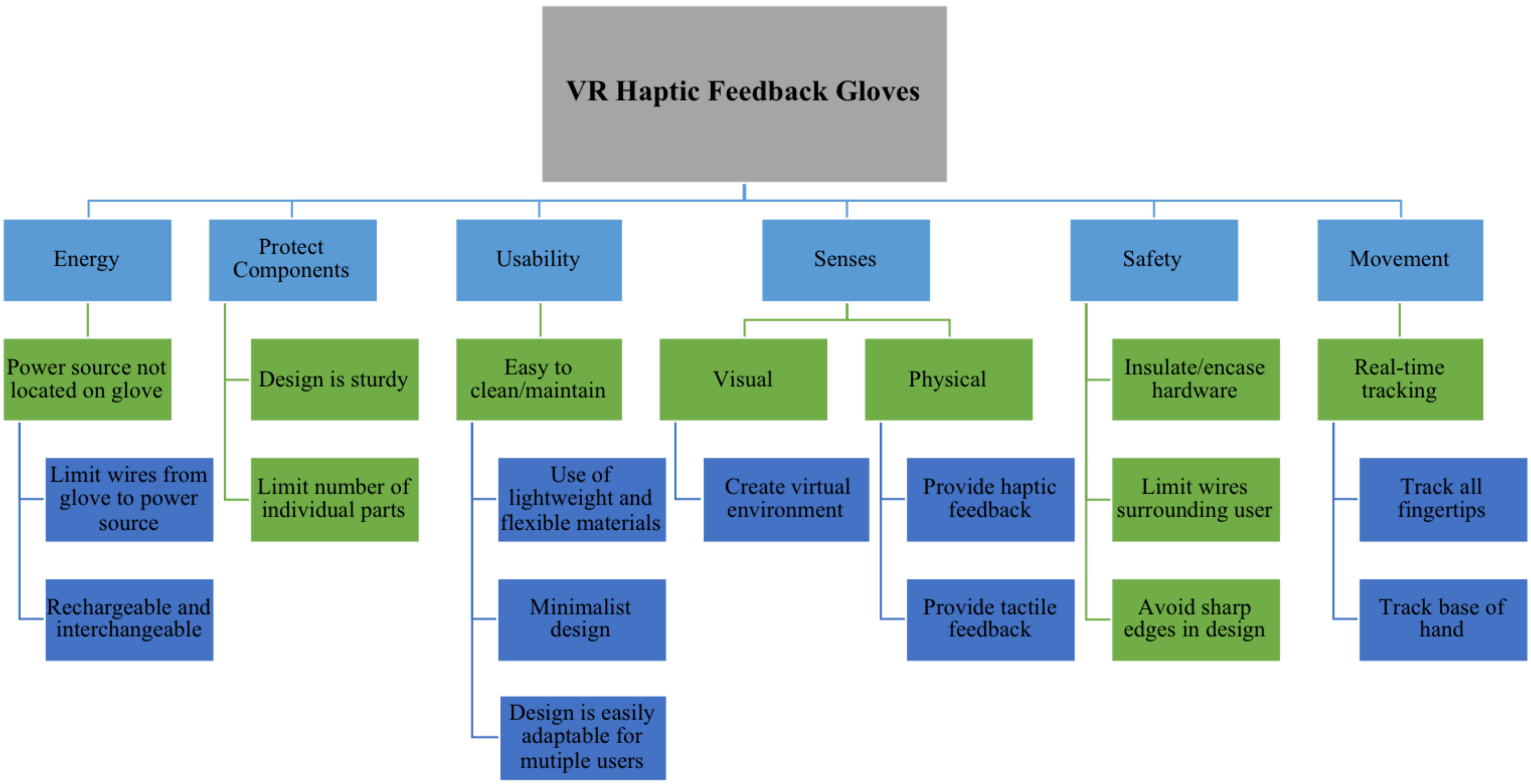


Figure 1. Functional Decomposition with major and minor functions.

1.4 Target Summary

All targets will be validated by testing the design. The latency will be measured as the time difference between the movement of the glove in reality and its depiction in the virtual environment. A signal will be sent from the gloves to the headset and the time difference will be measured. To test the battery, the gloves will simply be turned on with the battery attached and run until the battery dies. The gloves will be used in the virtual environment while they are on to simulate normal operating conditions. The heat observed by the user will be measured with an infrared thermometer to determine the change in temperature.

Both the tactile and haptic feedback will be tested in the same manner. Since there is no accurate way to quantify haptic feedback, it will simply be measured by whether the glove provides a recognizable sensation of touch. This will be tested by the team using our own discretion. All team members will interact with multiple parts of the environment and report whether the haptic feedback was recognizable. A durability test will be performed on the gloves by dropping them from a height of 4 feet on a hard surface. The functions of the gloves will then be evaluated to determine whether its operation has been compromised. To test for the glove weight target, the gloves will simply be placed on a scale to measure their weight in ounces. The target for the weight of each glove was chosen using available products as references. The maximum thickness of the gloves as well as the palm width will measured in inches using a Vernier caliper.

Table 2
Mission critical targets

Metric	Target
System latency	20 milliseconds
Tactile Feedback	Sensation of touch
Haptic feedback	Physical stimuli in response to VR environment

The most important targets and metrics for this project are the haptic feedback and the latency. The main goals of this project are to provide haptic feedback to the user and track both hands in real time, making these targets critical for completion. The tracking will determine whether the user is making contact with items in the virtual environment, and the haptic feedback will confirm for the user that they made the contact. The targets were determined based on direct needs of the customer. The targets for haptic and tactile feedback were chosen as simple yes or no constraints due to the inability to quantify these items and Lockheed Martin's need for recognizable versions of both. The latency target was selected as an achievable average of latency advertised for available virtual reality gloves. This value is accepted as a low enough latency to be undetectable by much of the population.

1.5 Concept Generation

Concept generation, otherwise known as ideation, is the process through which different design ideas are created. When creating a product, it is extremely beneficial to produce multiple rough draft design concepts that vary from one another. The first step in concept generation helps increase the likelihood of generating a novel design that produces fewer errors in the final outcome. The overall design can then be broken down into subsystems- where each subsystem holds different concepts that were generated.

The subsystems specific to this project include: tracking, haptic feedback, microcontroller, gloves, VR environment, and power source. These subsystems were created based upon the critical systems for completion of the project. Table 1, below, illustrates the different subsystems and the concepts generated. Following the table is background information for each of the concepts as well as three overall design concepts.

Table 3

Subsystem and concept descriptions

SUBSYSTEM	#	CONCEPT DESCRIPTION
Tracking	1	HTC Vive Lighthouse Base Station
	2	Inertial Measurement Unit (IMU)
	3	Motion tracking cameras
Haptic Feedback	1	Linear resonant actuators
	2	Microfluidic chambers
	3	Force feedback
Microcontroller	1	BeagleBone Black Wireless
	2	Raspberry Pi 3 Model B+
	3	Arduino MKR1000 WIFI
Glove	1	Baseball batting glove
	2	Golf glove
	3	Fingerless tactical glove
	4	Partial fingerless pilot glove
VR Environment	1	Fighter jet cockpit
	2	Helicopter gun seat
	3	Ground fighting armored vehicle driver's seat
Power Source	1	Wired connection to wall outlet
	2	Replaceable rechargeable battery
	3	Built-in rechargeable battery
	4	Replaceable alkaline battery

Tracking

Motion tracking is one of the most important components of an effective virtual reality experience. In the context of this project, tracking refers to the method used to determine the location of the hands and fingers in the physical realm as well as producing the necessary outputs to map this motion into the virtual reality environment. The main schemes used for tracking today are HTC's lighthouse technology, inertial measurement units (IMUs), and motion tracking cameras. These technologies can be used in combination with one another to create a tracking system with higher capabilities than the individual technologies are able to themselves.

<u>Concept 1: HTC Vive Lighthouse Base Station</u>

The HTC Vive Lighthouse Base Station is a powerful method of tracking that uses pulsing light, lasers, and photosensors to track objects in the virtual environment. The lightbox is a small cube shape with a series of LEDs and two sweeping lasers inside. The headset has several photo sensors spread over its surface. The box pulses the LEDs up to sixty times a second, then it sweeps the "play area" with the lasers. The sensors on the headset detect the flash of light from the box, the start counting until the laser hits the same sensors. This allows the box to calculate an object's exact position in 3-D space.

<u>Concept 2: Inertial Measurement Units (IMUs)</u>

Inertial Measurement Units are small sensors that use acceleration and orientation to track objects. IMUs generally consist of six sensors oriented on each axis of a three-dimensional coordinate plane. Each axis will have an accelerometer, which will measure specific force, and a gyroscope, which will track orientation. Some higher end IMUs are advertised as nine axis sensors and contain both sensors mentioned previously, plus a three-axis magnetometer. The magnetometer helps to compensate for any drift or noise in the data to help improve sensor accuracy.

Concept 3: Motion Tracking Cameras

Motion tracking cameras are a relatively simple method of tracking objects in 3-D space. Motion tracking via cameras can be done using either passive or active optical markers. To track objects in virtual reality using passive markers, all you need is a set of cameras and optical markers. The optical markers are reflective pieces of material and are placed around the entire surface of the object being tracked. The camera uses these markers, and the disparity between them, to calculate the object's position in space. Active optical markers are small LEDs that operate in the same manner as the passive markers and provide much higher accuracy.

Haptic Feedback

To signify when the user interacts with an item in the virtual environment (buttons, switches, etc.) some level of feedback is necessary. The feedback due to this virtual interaction will be denoted haptic feedback. This is an important distinction because tactile feedback must also be retained. Tactile feedback is the feedback due to the interaction with an item in the physical realm (steering wheel, joystick, etc.). Linear resonant actuators (LRA's), microfluids, or force feedback can be used alone or in concert to produce a variety of haptic feedback. Each of these technologies has different resolution and varying levels of complexity.

Concept 1: Linear Resonant Actuators (LRA's)

One of the most common methods of producing haptic feedback is using linear resonant actuators. These actuators are small cylinders that use vibration to generate feedback. The main components found in the cylinder are a moving mass, an electromagnet, and a spring. A current is delivered to the actuator which creates a magnetic field. This field pushes the mass upwards, while the spring attached to the mass attempts to return it to its equilibrium position. This movement within the cylinder causes the vibration which generates the haptic feedback. These are common in small electronics including phones and smart watches.

Concept 2: Microfluidic Chambers

One of the more advanced and in-depth methods of providing haptic feedback is using microfluidic chambers. This method consists of a network of microfluidic channels that run to each part of the glove. The feedback from the fluids can be employed using either pneumatic actuators or fluid chambers. To use the pneumatic actuators, fluid is run through the channels to the correct actuator. The fluid forces the actuator upwards, creating contact with the skin, and generating the feedback. To use the chambers, the fluid is run the same way, but instead of moving an actuator it fills a small bladder. This bladder inflates and makes contact with the skin providing haptic feedback.

Concept 3: Force feedback

Force feedback is a method of providing haptic feedback based on a mechanical system. In the application for our project, the system would consist of five arms and five motors. The motors would be placed on the back of the hand, attached to a mechanical linkage called an “arm.” One end of each arm will be attached to a motor, while the other end is attached to the tip of each finger. As the motor is driven, the arm will pull back on the finger, generating the haptic feedback. This method is often bulky and fragile, reducing its viability.

Microcontroller

Microcontrollers are small computers on a single integrated circuit that can be considered the brains of the system. They are designed for embedded applications and consist of many different components. A basic microcontroller contains processor cores, memory, and input/output connections.

The microcontroller will be responsible for the controls and coordination of the major systems involved in this project. The signals generated by the tracking will be processed by the microcontroller and sent to the VR system to display the hands in the virtual environment. The signals generated by the interaction with the virtual environment will be sent from the VR environment to the microcontroller. The microcontroller will then send the signal to activate the proper haptic feedback. The main power source will be connected to the microcontroller, which will also be the power source for the feedback and tracking components.

To choose the proper microcontroller, it will be important to compare the different features available in the market. Currently, there are many different companies offering development boards. The team will analyze the different features to select the development board that will best match the customer needs and targets.

Concept 1: BeagleBone Black Wireless

With a price tag of $75, the most expensive microcontroller selected for potential use in the project is the BeagleBone Black Wireless. This microcontroller comes ready with 4 GB of on-board memory and an ARM Cortex-8 processor which operates at 1 GHz. This microcontroller is equipped with 802.11 b/g/n 2.4 GHz WiFi as well as Bluetooth 4.1 with BLE wireless network capabilities. It operates at 5 volts and the physical dimensions of the board are 3.4 inches by 2.1 inches.

Concept 2: Raspberry Pi 3 Model B+

The Raspberry Pi 3 Model B+ measures 3.35 inches by 2.2 inches and it has an operating voltage of 5 V. It comes with 1 GB of on-board memory as well as an SD card slot for additional memory capability. With a price of $35 it is less than half the cost of the BeagleBone Black Wireless. The on-board processing unit is a 1.4 GHz ARM Cortex-8. For wireless communications, the Raspberry Pi 3 Model B+ can utilize 2.4GHz and 5GHz 802.11.b/g/n/ac WiFi as well as Bluetooth 4.2 with BLE.

Concept 3: Arduino MKR 1000 WiFi

The Arduino MKR 1000 WiFi is the smallest board of the three selected, measuring at just 2.4 inches by 1 inch. With it being the smallest board, it naturally has the least amount of on-board memory with 256 KB. The wireless communication facilitated by this microcontroller is done with 2.4GHz 802.11 b/g/n WiFi. The ARM Cortex-M0+ running at 48 MHz is the boards processing unit, and the entire microcontroller unit costs $35 like the Raspberry Pi 3 Model B+.

Table 4
Microcontroller Specifications

Microcontroller	Operating Voltage (Volts)	Size (inches)	On-Board Memory Storage	Processor	Cost	Communications
BeagleBone Black Wireless	5	3.4 by 2.1	4 GB	1 GHz ARM Cortex-A8	$75	802.11 b/g/n 2.4GHz WIFI and Bluetooth 4.1 with BLE
Raspberry Pi 3 Model B+	5	3.35 by 2.2	1 GB plus micro SD card slot	1.4 GHz ARM Cortex-A8	$35	2.4GHz and 5GHz 802.11.b/g/n/ac WIFI and Bluetooth 4.2 with BLE
Arduino MKR1000 WIFI	5	2.4 by 1	256 KB	48 MHz ARM Cortex-M0+	$35	2.4GHz 802.11 sb/g/n WIFI

Glove

The glove will have a few important functions in the context of this project. The first being to house all the components of the system that need to be located on the hand, namely the tracking sensors and the device(s) to produce the haptic feedback. Another important aspect is the glove material itself. The material needs to be thin enough to allow for retention of tactile feedback, but robust enough to stand up to rigorous use. The glove must also be constructed in such a way that it allows for periodic sterilization. Taking these factors into account, the concepts generated for the glove type are baseball batting gloves, golf gloves, fingerless tactical gloves, and partial fingerless pilot gloves.

Concept 1: Baseball Batting Glove

Baseball batting gloves are used by baseball players use for increased grip while batting. The gloves are typically made with a leather palm and synthetic material for the back of the hand. They offer relatively high breathability to increase comfort for the user. These gloves are generally form fitting with an adjustable band on the wrist. They are relatively thin, presenting the opportunity for the inclusion of tactile feedback despite the fully covered fingertips.

Concept 2: Golf Glove

Golf gloves are thin leather gloves used to increase grip for golfers. Like baseball gloves, golf gloves are form fitting and offer high breathability. They have an adjustable Velcro strap on the back in order to adjust size. These gloves are thin and will only have a small reduction of required tactile feedback. Since these gloves are made nearly entirely of leather, moisture over an extended period of time can lead to pungent smells and dirt buildup.

Concept 3: Fingerless Tactical Glove

Tactical gloves are common amongst military personnel and are often considered standard issue. These gloves are generally made of durable fabrics including neoprene and microfiber. They come in many forms, most of them boasting high levels of protection and durability. This increase in sturdiness comes with a corresponding increase in bulkiness, difficulty in interacting with objects, and lack of maneuverability. Some of these gloves are fingerless in order to reduce this difficulty in interaction. This would be beneficial for our project because it would offer the sturdiness required to support the electrical components, and the free fingertips to experience the tactile feedback.

Concept 4: Partial Fingerless Pilot Glove

Pilot gloves, as the name suggests, are gloves worn by pilots to help with gripping joy sticks and steering wheels. These gloves are generally thick and sturdy, often made of wool or thick cloth. The palms and insides of the fingers are most often made of leather to help with grip. Some models have the fingertips of the middle finger, index finger, and thumb removed in order to help with precision operation of smaller controls. This lack of fingertips would help provide the necessary tactile feedback for our gloves.

Environment

A virtual reality environment, similar to video games, provides visual sensory stimulation in a closed sensory environment. This is achieved by isolating the user from their environment, while using a graphics engine to emulate objects from the real world. The user can interact with these objects in the virtual environment that are designed to resemble real-world motion, movement, and mechanics.

The virtual environment will be displayed to the user through an HTC Vive Headset. The headset is connected to a high-speed computer where the virtual environment is built using a game engine such as Unity or Unreal.

In our Virtual Reality environment, the user’s hands will be tracked and displayed in real-time as they interact with various objects. Based on the object’s structure that the user interacts with, haptic feedback will be applied to the gloves.

Concept 1: Fighter Jet Cockpit

This environment will simulate the cockpit of a fighter jet, where the user will be seated in a physical seat and be given a physical joystick, similar to the joystick used in an actual fighter jet cockpit. The system will display the control panel of the fighter jet in the user's headset, making the panel seem as if it’s right in front of the user. To allow for a realistic training experience, the simulated control panel will accurately represent a control panel that would be found in a real-world fighter jet of the same model.

Concept 2: Helicopter Gun Seat

This environment will simulate the gun seat in an attack helicopter. The user will be seated in a physical seat and be given a physical control. The system will display the control panel of the helicopter in the user's headset, making the panel seem as if it’s right in front of the user. To allow for a realistic training experience, the simulated control panel will accurately represent a control panel that would be found in a real-world helicopter of the same model.

Concept 3: Ground Fighting Armored Vehicle Driver’s Seat

This environment will simulate the driver’s seat in a ground fighting armored vehicle. The user will be seated in a physical seat and be given a physical steering wheel. The system will display the control panel of the ground vehicle in the user's headset, making them appear as if it’s right in front of him/her. The control panel will accurately correspond to the control panel in a real ground vehicle of the same model, allowing for the most realistic training experience for the user.

Power Source

The power source will be responsible for providing the microcontroller with the energy required to coordinate all the critical systems involved. It should have enough capacity to last for the duration of a training exercise and potentially be exchanged, recharged, or both. The size and weight of the power source will also impact the decision-making process, as well as the amount of wires needed.

Concept 1: Wired Connection to Wall Outlet

One potential method of providing power to the gloves is simply plugging them into a wall outlet. There are generally multiple outlets in any given room in a building, which provide a constant flow of power. This method would reduce any problems associated with insufficient power supply. Unfortunately, this method greatly reduces mobility and increases safety risks due to the addition of loose wire running from the gloves to the wall.

Concept 2: Replaceable Rechargeable Battery

One method of reducing wires running to an auxiliary power source is to simply include the power source on the glove. This can be done with a rechargeable battery that can be removed from the glove. The battery would most likely be around 5 volts in order to maintain a small size and provide the rated voltage. The battery will be clipped into place so that it can be removed and recharged. This would allow trainees to easily swap out their battery instead of having to completely change gloves.

Concept 3: Built-in Rechargeable Battery

Using a built-in rechargeable battery also solves the issue of running wires to an auxiliary power source. This would be the same battery as the removable one, but it would be fixed on the glove. It would have a charging port on the glove and would require trainees to remove the glove for charging. While this is a viable option, it is less efficient than having a removable battery.

Concept 4: Replaceable Alkaline Battery

A very simple solution to hardwiring the gloves to an auxiliary power source is to power them using disposable alkaline batteries. A battery sufficient to power the gloves would be chosen based on the electrical components chosen. The batteries would be place in a receptacle with a positive and negative terminal. Once the batteries died, they would simply be replaced with fresh ones. This method is much costlier than the others, requiring a plethora of alkaline batteries. It also offers challenges associated with housing the batteries and inefficiency in swapping them.

Design Concepts

After generating concepts for each subsystem, the team can begin generating overall design concepts. As we move forward into design selection, a few of the concepts will be discarded as they do not completely align with the customer needs and targets. Using micro fluids for haptic feedback would provide a very high resolution of feedback but would also be extremely bulky. Based on the need for a portable, lightweight system that retains real life tactile feedback this method of producing haptic feedback would not meet our requirements. Force feedback is another method of haptic feedback that is ill-suited for our application. This would be bulky and not provide the type of haptic feedback that the customer is looking for. Therefore, we can eliminate its usage in our overall design and conclude that linear resonant actuators will be used to produce the haptic feedback. The three design concepts below only consider the type of glove, the type of tracking, and the type of haptic feedback.

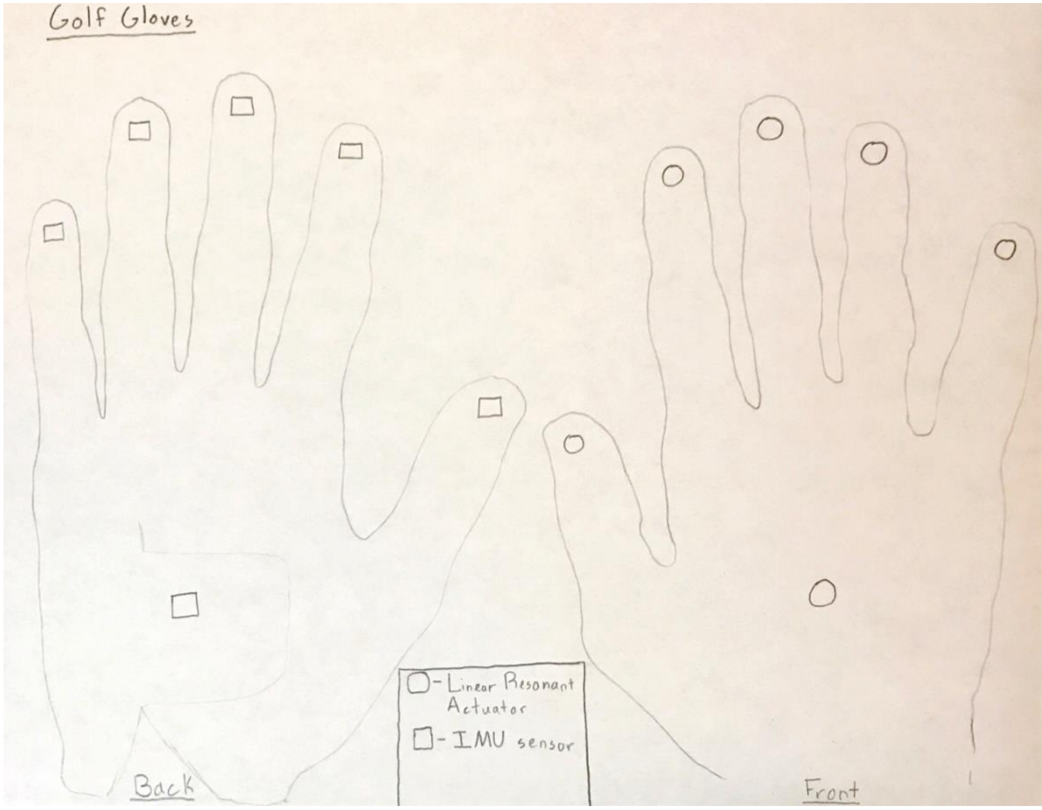


Figure 2. Golf glove, IMU sensors, and linear resonant actuators

The first concept generated utilizes the golf glove as the glove type for the electronics to be mounted on in order to achieve a sleek profile and to keep from interfering with the tactile feedback. For tracking, this concept uses IMU sensors on the back of the hand (palm side down) to allow for motion tracking of the palm and fingers. The linear resonant actuators are on the front of the hand (palm side up) to allow for the haptic feedback. The exact placement of the actuators and sensors are not set in stone with respect to the scale of the drawing since further testing still needs to be completed. Testing will be done to determine a position that allows for full range of motion for the hand, minimal tactile feedback interruption, and maximum haptic feedback.

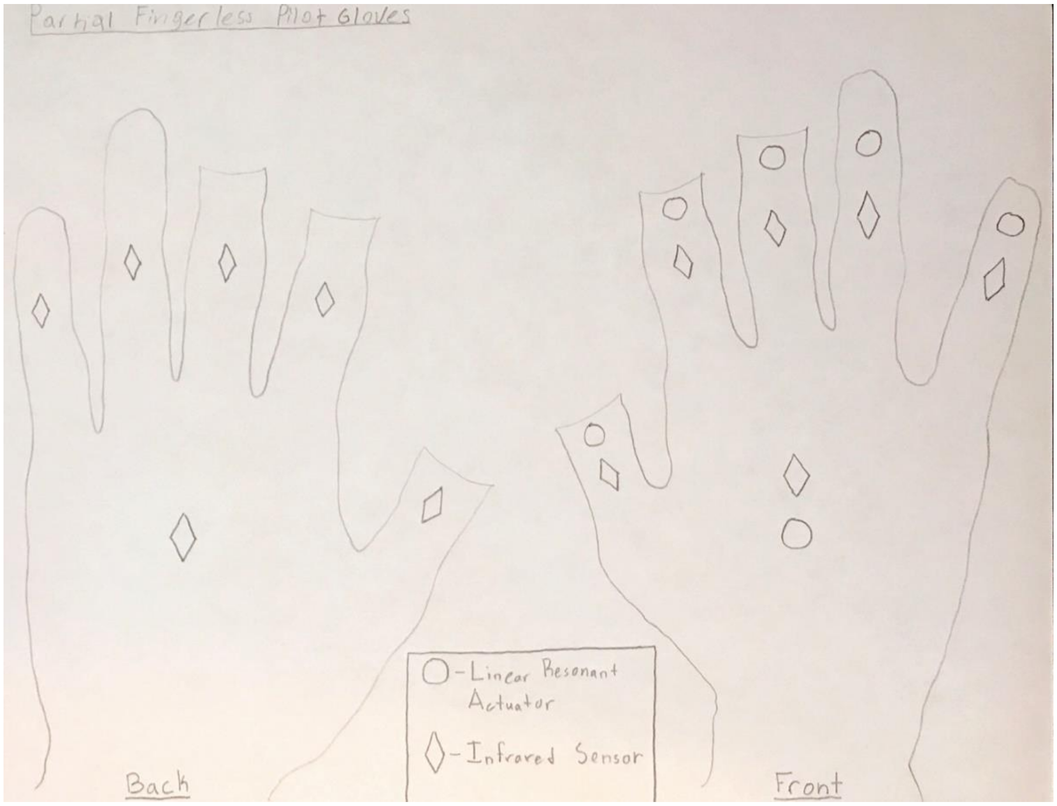


Figure 3. Partial fingerless pilot’s glove, infrared sensors, and linear resonant actuators.

The second concept that was generated uses a partial fingerless pilot’s glove as the housing for the electronics. The concept utilizes infrared sensors on both sides of the hands for motion tracking and linear resonant actuators to provide the haptic feedback. This glove will allow the user to have some tactile feedback since the first two fingers and thumb are fingerless. The actuators will be placed at the base of the knuckles to provide feedback, but testing will need to be performed to determine optimal placement. The infrared sensors will have to be on both sides of the hands in order to ensure that signal is always received regardless of the orientation of the hand.

If the hand is upside down and the sensors are only on the backside of the hand, then the signal may be interrupted.

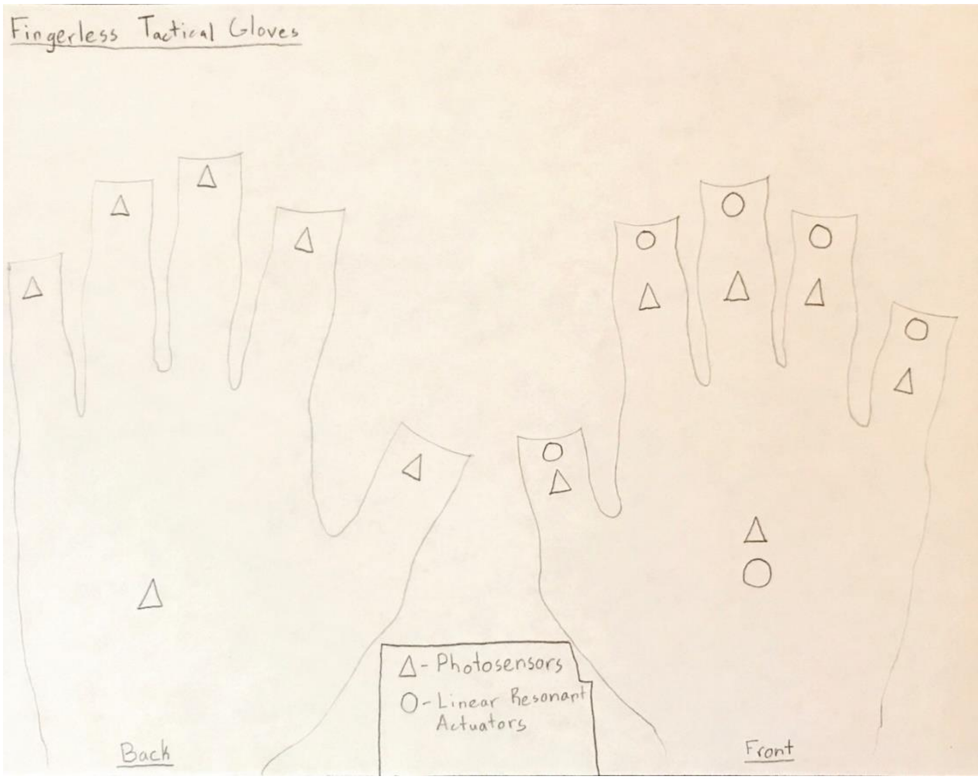


Figure 4. Fingerless tactical gloves, photo sensors, and linear resonant actuators.

The third design consists of tactical gloves that are fully fingerless as the housing for the photo sensors on both sides of the hands for motion tracking, and linear resonant actuators on the front of the hand. This design allows for the highest degree of tactile feedback since the user can feel the physical controls on each of the fingers with the fingerless glove design. The photo sensors must be on both sides of the hands in order to allow the hands and fingers to be tracked regardless of hand orientation. The actuators will be placed at the base of the knuckle of each finger. However as mentioned, further testing will be performed to find the ideal location on each finger.

1.6 Concept Selection

Concept selection, the process following Concept Generation in the Design Process, is the process of evaluating generated concepts with respect to the customer's needs and studying each concept's strengths and weaknesses in comparison to each other. Through Concept Generation, all design concepts created are evaluated and the top designs were used for further analysis within Concept Selection. For simplification and organization, a matrix is used to display the different concepts and design components and compare them to highlight the best concepts.

For this specific project, we utilized a morphological chart and narrowed down three design concepts to use in the final concept selection process. For our concept selection, we used both a Pugh Matrix and House of Quality. The Pugh Matrix was used to evaluate and compare the top three selected designs and their components against a datum, which for this project was a current, on-the-market product called *Senso Gloves*. The House of Quality was used to define the relationship between the customer needs and the concept/component capabilities.

Table 5

House of Quality for Gloves

		Engineering Characteristic			
Improvement Direction		↓	↑	↓	↑
Customer Requirements	Importance Weight Factor	Size	Effectivenes s of feedback	interference with tactile feedback	Durability
Weight	7.4	5		5	
Effectiveness	17		9		
Cost	6.51		1		5
Durability	20.2	1		5	9
Size	3.4	9			
Raw Score (600.15)		87.80	159.5	138.0	214.4
Relative Weight %		14.63	26.58	22.99	35.72
Rank Order		4	2	3	1

The figure above (Table 5) is the House of Quality used for the selection process for the gloves. The engineering characteristics used for the figure were glove thickness, haptic feedback, tactile feedback, and durability. These were listed against the customer requirements collected from our sponsor to determine the most important engineering characteristics. Although glove thickness had the highest relative weight, the team decided that tactile and haptic feedback were the most important characteristics. This decision was made because of the needs expressed by the customer. Glove thickness is a contributing factor to tactile feedback, strengthening the apparent importance. Due to the limited number of engineering characteristics, they were all used in the Pugh chart selection stage.

Table 6

House of Quality for Tracking

		Engineering Characteristics		
Improvement Direction		↓	↓	↑
	Units	ms	in	n/a
Customer Requirements	**Importance Weight Factor**	**Latency**	**Size**	**complexity**
Size	**15.2**		9	
Accuracy	**10.4**	9		9
Time	**20.0**			9
Cost	**1.33**	5	5	5
	Raw Score (524.1)	100.3	143.5	280.3
	Relative Weight %	19.13	27.38	53.49
	Rank Order	1	3	2

A house of quality was also created for the tracking method to determine the most important engineering characteristics to carry over into the next stage of the selection process. The customer requirements for this subsystem were size, accuracy, time to implement the system, and cost. The engineering characteristics associated with this subsystem were latency, size, and complexity. After calculating relative weight percentage, it was determined that complexity would be the most important characteristic based on our customer needs. Generally speaking, the more complex the tracking system is, the more accurate it will be. For our application, we are looking for a less complex tracking system, based on the lack of importance of latency. All of the engineering characteristics were carried over for the Pugh charts in the next step of the selection process.

Table 7

House of Quality for Power Supply

		Engineering characteristic		
Customer Requirements	**Importance Weight Factor**	**Battery life**	**Power delivered**	**Size**
Weight	**6.20**	5	5	9
Range of Motion	**10.2**	1	1	5
Efficiency	**6.11**	5	5	5
Raw Score (280.9)		71.75	71.75	137.4
Relative Weight %		25.55	25.55	48.91
Rank Order		1	1	3

The house of quality above was used to help determine the most important engineering characteristics for the power supply subsystem. The customer needs were given as weight, range of motion, and efficiency. The associated engineering characteristics were battery life, power delivered, and size. Size was found to be the most important characteristic based on its high relative weight a score. This fits with our customer needs in that increased weight would reduce range of motion which was the most important customer requirement. All three engineering characteristics were used in the Pugh chart for the next step of the selection process.

Table 8
House of Quality for Haptic Feedback

		Engineering Characteristic			
Customer Requirements	**Importance Weight Factor**	**Size**	**Effectiveness of feedback**	**interference with tactile feedback**	**Durability**
Weight	**7.4**	5		5	
Effectiveness	**17**		9		
Cost	**6.51**		1		5
Durability	**20.2**	1		5	9
Size	**3.4**	9			
Raw Score	(600.15)	87.80	159.5	138.0	214.4
Relative Weight %		14.63	26.58	22.99	35.72
Rank Order		4	2	3	1

Table 8 above is the house of quality done for the haptic feedback subsystem. The stated customer needs were effectiveness of the feedback, cost, durability of the subsystem, and total size. The corresponding engineering characteristics were the size of the subsystem, the effectiveness of the feedback, interference with tactile feedback, and durability. Durability, which includes the sturdiness and structural integrity of the subsystem, was determined to be the most important characteristic based on its high relative weight. It was decided that all the engineering characteristics listed were important enough to carry on to the next stage of the selection process because they all have a significant impact on haptic feedback.

Table 9

House of Quality for Microprocessor

		Engineering Characteristics			
Improvement Direction		↓	↓	↑	↑
Units		W	in	bytes	Hertz
Customer Requirements	**Importance Weight Factor**	**Power Consumption**	**Size**	**Memory**	**Processing Power**
Size	**5.5**		9	1	5
Cost	**2.33**		5		9
Processor	**7**	1	1		9
Memory	**4.5**	1	9	9	
Raw Score (277.6)		11.50	108.7	46.00	111.5
Relative Weight %		4.10	39.1	16.6	40.2
Rank Order		4	2	3	1

The final house of quality constructed was to determine the most important engineering characteristics for the microcontroller. Since there weren't explicitly stated customer requirements for this subsystem, the team designated desirable qualities. These qualities were size, cost, processor, and memory. The associated engineering characteristics for the microcontroller were power consumption, size, memory, and processing power. After calculating relative weight percentage for each characteristic, it was determined that size and processing power were the most important. They received very similar relative weights, showing almost equal importance. The microcontroller needs to be powerful enough to run the gloves, but small enough to not impede mobility.

Gloves:

The different types of gloves were also evaluated in a Pugh chart to determine the best type of glove to use. The datum used in this chart were the fingerless tactical gloves. The other concepts used were golf gloves, fingerless pilot gloves, and baseball batting gloves. Each of these types of gloves were compared to the fingerless gloves using the characteristics determined by the house of quality. Both the golf gloves and the batting gloves were found to be thinner than the fingerless gloves but also less durable and would provide less tactical feedback but would provide better haptic feedback since the haptic feedback system could be better integrated into these gloves. The fingerless gloves however lost to the partial fingerless pilot's gloves since these were determined to be more durable and provide better haptic feedback and better tactical feedback.

Table 10
Pugh Matrix for Gloves

	Baseline	**Alternative Solution**		
Criteria	Datum: Fingerless Gloves	Concept 1: Golf Gloves	Concept 2: Partial fingerless pilots gloves	Concept 3: Batting Gloves
Max glove thickness	DATUM	+	S	+
Tactile Feedback		-	-	-
Haptic feedback		+	+	+
Durability		-	+	-
Sum of Positives		2	2	2
Sum of Negatives		2	1	2

Tracking:

The datum selected as the benchmark for the tracking were the IMU sensors. Machine learning, photo sensors, and infrared sensors were then compared to the benchmark using the selection criteria determined by the house of quality. The photo sensors and the infrared sensors would require twice as many sensors as the IMUs for a barely noticeable change in latency or effectiveness. Machine learning was a viable way for the tracking of the hands and fingers, but the amount of time needed to implement it and its complexity outweighs any potential benefits. The IMU sensors were determined to be the best concept since they would be the most effective while keeping cost, complexity and size down.

Table 11
Pugh Matrix for Tracking

	Baseline	**Alternative Solution**		
Criteria	Datum: IMU	Concept 1: Machine Learning	Concept 2: Photo Sensors	Concept 3: Infared Sensors
Latency	DATUM	-	S	S
Size		S	-	-
Complexity		-	-	-
Sum of Positives		0	0	0
Sum of Negatives		2	1	2

Power Supply:

To determine the best option for the power supply, a Pugh matrix was employed using an encased rechargeable battery as the datum. The outcome of this process established a wired connection as the best option because it had the highest score. It is the lightest, smallest, and has the longest lifetime. While the wired connection received the highest score, it was not selected as the best option. The removable, rechargeable battery was determined to be the most viable option. This was decided based on given customer requirements. The user needs to have a full range of motion of his/her hands and the gloves need to have no wires running to external devices. The wired connection violated both requirements. The removable, rechargeable battery had the same number of pluses and minuses as disposables, but is more efficient and cost effective, making it the best option.

Table 12
Pugh Matrix for Power Supply

	Baseline	**Alternative Solution**		
Criteria	Datum: Encased Rechargable	Concept 1: Wired Connection	Concept 2: Removable Rechargable	Concept 3: Disposable Batteries
Weight	DATUM	+	-	-
Battery Life		+	+	+
Power Delivered		S	S	S
Size		+	-	-
Sum of Positives		3	1	1
Sum of Negatives		0	2	2

Haptic Feedback:

To assess the viability of the different methods of providing haptic feedback, the concepts were compared in a Pugh chart with Linear Resonant Actuators (LRA) as the datum. Force feedback, relative to LRA, is going to be able to provide more levels of effective feedback to the user. With the added feedback levels comes added complexity, reduced durability, and interference with tactile feedback. Force feedback systems are also substantially more sizeable than systems which employ LRA. The same comparisons can be made between LRA systems and microfluidic based systems. With micro fluids the highest level of haptic feedback resolution can be reached. This haptic feedback resolution is produced by bladders all over the hand which essentially insulate the user from any interaction with the physical world, preventing effective tactile feedback. The microfluid based system is also bulky and has increased complexity. The size and construction result in lower durability than the other methods.

Table 13
Pugh Matrix for Haptic Feedback

	Baseline	**Alternative Solution**	
Criteria	Datum: LRA	Concept 1: Force feedback	Concept 2: Microfluids
Size	DATUM	-	-
Effectiveness of Feedback		+	+
Interruption of Tactile Feedback		-	-
Durability		-	-
Sum of Positives		1	1
Sum of Negatives		3	3

Microcontroller:

The datum selected as the benchmark for comparison in the microcontroller the Pugh chart is the Raspberry Pi 3 Model B+. The BeagleBone Black Wireless and the Arduino MKR1000 Wi-Fi were then assessed with respect to the Raspberry Pi. The BeagleBone is a similar physical size but has less processing power and costs over twice as much. The higher price does come with an increase in onboard memory, but its processer is clocked at a lower speed than the Raspberry Pi. The Arduino MKR1000 Wi-Fi is the smallest of the options with a footprint less than 50% the size of the other two microcontrollers analyzed here. The smaller size comes with sacrifices to both onboard memory and processing power when compared to the datum.

Table 14

Pugh Matrix for Microcontroller

	Baseline	**Alternative Solution**	
Criteria	Datum: Raspberry Pi 3 Model B+	Concept 1: BeagleBone Black Wireless	Concept 2: Arduino MKR1000 WiFi
Size	DATUM	S	+
Cost		-	S
Processor		-	-
Memory		+	-
Sum of Positives		2	2
Sum of Negatives		2	1

Final Decision

After each Pugh chart was completed and the necessary analysis was done, the best option for each subsystem was chosen. These were then compiled to create the final design concept. The best option for the gloves were the partial fingerless pilot gloves. These were chosen because they offer the highest level of tactile feedback and are very durable. The extended wrist portion can also help with electronics mounting. IMUs were selected as the best option for tracking due to their small size, high accuracy, and low level of complexity. While the resolution of the IMUs is lower than that of the machine learning, it is much more time efficient to implement.

For the power supply subsystem, a removable, rechargeable battery. The data from the Pugh chart established a hard-wired power connection as the best option, but it was not a viable choice based on our customer requirements. It is essential that the user has full mobility with his hands. A wired connection reduces this mobility and adds an extra obstacle in glove transfers between users. For the haptic feedback subsystem, the LRAs were chosen as the best option. This choice was made since the LRAs are smaller, more durable, and provided less interference to tactile feedback. The quality of feedback is slightly lower for LRAs compared to other methods, but since our application does not require incredible realistic feedback, it the obvious choice. The number of LRAs and their positions on the gloves will be determined during the prototyping and testing stage.

The Raspberry Pi 3 Model B+ was chosen as the microcontroller due to its processing and memory capabilities combined with on-board wireless communications. Coming standard with

2.4GHz and 5GHz 802.11.b/g/n/ac WIFI and Bluetooth 4.2 with Bluetooth Low Energy (BLE), the Raspberry Pi has the communications protocols necessary to effectively and efficiently process and transmit data throughout our system. These components will be combined to create the final product, a pair of virtual reality gloves that provide accurate tracking and haptic feedback for military training simulations.

1.7 Project Plan

The project plan sets the schedule for the Spring semester. It includes the detailed design phase and all the necessary deadlines to complete the design before Engineering Design Day on April 18th.

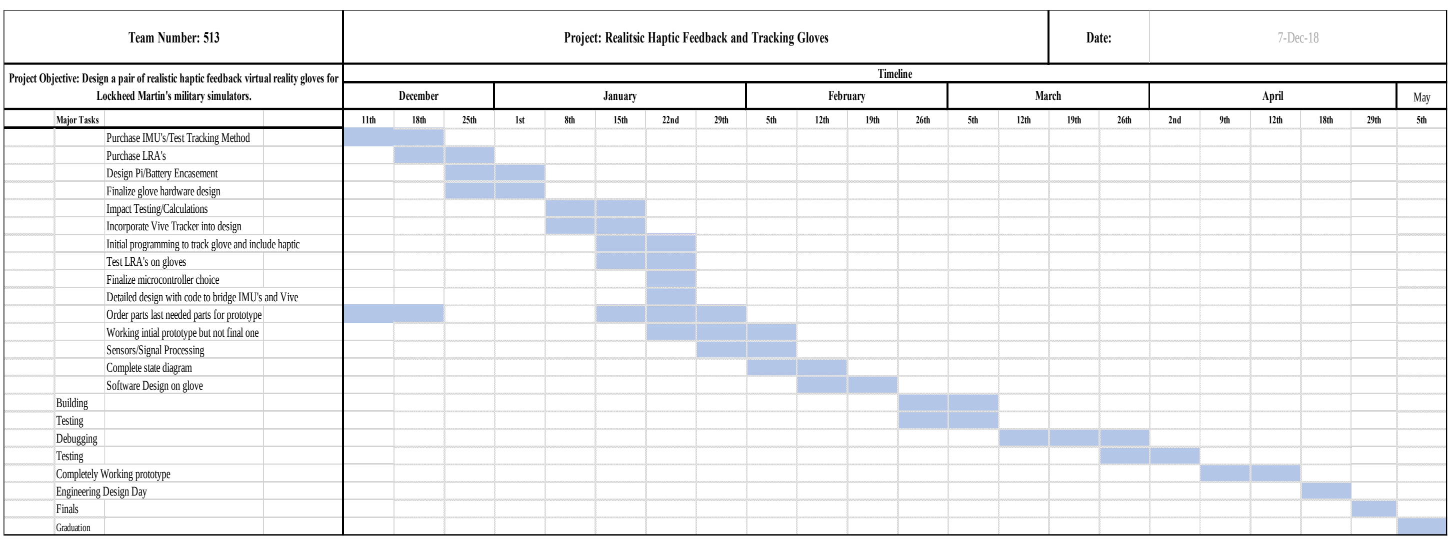


Figure 5: Gantt chart to outline spring project plan in detail.

Purchase IMU's/Test Tracking Method– December 13th

The IMU's are one of the most essential systems in this design. The earlier these are ordered the more time will be spent to ensure that the parts of the hand can be tracked in the virtual environment.

Purchase LRA's – December 21st

Purchase LRA's so that we will have them when they are needed for integration with the IMU's.

Design Pi/Battery Encasement – December 30th

Design encasement for the batteries and the microcontroller to be attached to the back of the glove.

Finalize glove hardware design – December 30th

Finalize how all hardware will be integrated onto the glove to allow for easy use as well as determine any additional hardware that will be needed.

Impact Testing/Calculations – January 8th

Determine durability of the glove and encasement using stress analysis.

Incorporate Vive Tracker into design – January 8th

Finalize location of Vive tracker on the glove.

Initial programming to track glove and include haptic – January 15th

Once a method for tracking an individual IMU has been finalized it will be implemented with all the IMU's on the glove to track each finger and hand. The haptic feedback will also be integrated in this step to ensure that the feedback occurs when it is needed.

Test LRA's on gloves – January 20th

Once the haptic feedback works the ideal location for the LRA's on the glove will be determined and then implemented.

Finalize microcontroller choice – January 20th

Explore any alternative methods that can be used for the microcontroller that can decrease any unnecessary bulk. If none can be found continue with the current microcontroller.

Detailed design with code to bridge IMU's and Vive – January 22nd

Ensure that the other hardware parts can communicate with the Vive tracker and that the gloves are useable with the unity game engine.

Order parts last needed parts for prototype – January 25th

Order any other extra parts that may be needed to develop a prototype.

Working initial prototype but not final one – January 30th

Create an initial prototype that works with unity and has all the necessary tracking and feedback capabilities.

Testing/ Debugging – March 1st

Test and debug the prototype until the final design has all necessary features and there are no issues with use.

Final Working Prototype – April 12th

Have a final working prototype ready for demo on engineering design day.

Chapter Two: EML 4552C

2.1 Restated Project Definition and Scope

The objective of this project is to mount and program electronic hardware onto a pair of gloves, which will be used for Lockheed Martin's military training programs to introduce a new, alternative training method through Virtual Reality. The key goals for this project are to make the gloves portable, lightweight, and durable. The gloves will have full mobility and will provide haptic feedback, or vibrational responses, for the palms of both hands and all ten fingers to the user during their training simulation. The gloves will be tracked in real time using code and hardware implemented by the team.

2.2 Final Design Revision

After the final design was decided there were some issues that the team addressed with regards to tracking, mounting onto the gloves, as well as the microcontroller that will be used. Initially the tracking system that was decided was the IMU sensor network. However, using this method it can be difficult to capture the angle of bend exhibited by the fingers. To capture their bend, flex sensors will be placed along each finger. These sensors are essentially resistors that have a varying resistance depending on the angle the finger is bent. These changes in resistance can then be used to map a more accurate representation of the hand than can be achieved solely with IMUs.

The glove type originally selected was also changed. After the partial fingerless pilot's gloves were selected a better glove option was found and incorporated into the final design. This new glove has pockets and straps already manufactured on the glove. These straps and pockets will make the mounting onto the gloves much easier, so they were used instead.

The final change to the design is the microcontroller that was used. Originally the microcontroller that was used was a Raspberry Pi 3 Model B+. This controller was too large and had too many unnecessary ports. The team decided to change to the Raspberry Pi Zero. This is a smaller board that has only the necessary pins and cuts down on the bulk that the Model B+ added to the overall system.

Appendix A: Code of Conduct

Mission Statement

Team 513 is committed to ensuring a positive work environment that supports professionalism, integrity, respect, and trust. Every member of this team will contribute a full effort to the creation and maintenance of such an environment in order to bring out the best in all of us as well as this project.

Team Roles

Each team member is delegated a specific role based on their experience and skill sets and is responsible for all here-within:

Project Manager- Alexandra Hollabaugh:

Manages the team as a whole; develops a plan and timeline for the project, delegates tasks among group member according to their skill sets; finalizes all documents and provides input on other positions where needed. The project manager is responsible for promoting synergy and increased teamwork. If a problem arises, the project manager will act in the best interest of the project.

Furthermore, he/she manages the budget and maintains a record of all credits and debits to project account. Any product or expenditure requests must be presented to the manager, whom is then responsible for reviewing and the analysis of equivalent/alternate solutions. They then relay the information to the team and if the request is granted, order the selection. A record of these analyses and budget adjustments must be kept.

He/she keeps the communication flowing, both between team members and Sponsor/Advisor. The project manager takes the lead in organizing, planning, and setting up of meetings. In addition, he/she is responsible for keeping a record of all correspondence between the group and 'minutes' for the meetings. Finally, he/she gives or facilitates presentations by individual team members and is responsible for overall project plans and progress.

Test Engineer- Jake Kennedy:

Works with the Hardware Engineer, Software Engineer, and Systems Engineer to help build, debug, and test the project at each stage of development. He works on the mechanical design aspects of the project while keeping the line of communication open between Mechanical and Electrical components of the design.

Systems Engineer- Alex Erven:

Works to integrate software with hardware into one desired result. The Systems Engineer is responsible for collaborating with the Software Engineer throughout the programming aspects of the project. He is also responsible for knowing necessary components of the project and how different systems work accordingly. The Systems Engineer will also work alongside the Project Manager in order to think of a long-term outcome/bigger picture instead of one step at a time to avoid errors.

Hardware Engineer- Jonathan Roberts:

Takes charge of the mechanical design through parts and material selection research. He is responsible for knowing the details of the design and presenting the options for each aspect to the team for the decision process. He keeps all design documentation for record and is responsible for gathering all reports.

Software Engineer- Kevin Lindquist:

He is responsible for project website development and majority of the programming needed for the project. He will work alongside the Lead Systems Engineer in order to maximize efficiency of both roles. He keeps all Electrical design documentation for record.

All Team Members:

- Work on certain tasks of the project
- Will assist other team members when necessary to ensure a positive final outcome
- Will provide all documentation and records to each member of the team (there will be no division between mechanical and electrical aspects)
- Buys into the project goals and success
- Delivers on commitments
- Adopt team spirit
- Listen and contribute constructively (feedback)
- Be effective in trying to get message across
- Be open minded to others ideas
- Respect others roles and ideas
- Be ambassador to the outside world in own tasks

Other Duties

Any duties not mentioned above will be dealt with on a case-to-case basis in accordance with unanimous group member agreement. These duties will be assigned based on each group member's applicable skills and free time to complete assigned duties. In the event that a task is not suited to any particular team member, or no team member has excess time to complete the task, it will be completed by the team as a whole.

Communication

The main form of communication will be over phone and text-messaging among the group, preferably phone as well as through regular meetings of the whole team. Email will be a secondary form of communication for issues not being time-sensitive. For the passing of information, i.e. files and presentations, email/OneDrive will be the main form of file transfer and proliferation.

Each group member must have a working email for the purposes of communication and file transference. Members must check their emails at least twice a day to check for important information and updates from the group. Although members will be initially informed via a phone call, meeting dates and pertinent information from the sponsor will additionally be sent over email so it is very important that each group member checks their email frequently.

If a meeting must be canceled, an email must be sent to the group at least 24 hours in advance.

Any team member that cannot attend a meeting must give advance notice of 24 hours informing the group of his absence. Reason for absence will be appreciated but not required if personal. Repeated absences in violation with this agreement will not be tolerated.

Attendance Policy

If a meeting must be canceled, an email must be sent to the group at least 24 hours in advance. Any team member that cannot attend a meeting must give advance notice of 24 hours informing the group of his absence. Reason for absence will be appreciated but not required if personal. Repeated absences in violation with this agreement will not be tolerated.

The team will meet with their sponsor every Tuesday at 4:00 pm and as a team every Thursday at 4:00 pm. In the event that there is an unforeseen time conflict with either a team member and/or the sponsor, the team will either reschedule the meeting or choose to still hold the meeting- this decision will be made by the team as a whole, depending on if majority of the team members will still be present. In an unexpected event such as this, the absent team member(s) will not be penalized but will be noted.

On the other hand, if a team member has more than 3 repeated absences with no reasonable justification, the team will seek external assistance by contacting the instructor and notifying him/her of the team member’s repeated absences.

Team Dynamics

The students will work as a team while allowing one another to feel free to make any suggestions or constructive criticisms without fear of being ridiculed and/or embarrassed. If any member on this team finds a task to be too difficult, it is expected that the member will ask for help from the other teammates. If any member of the team feels they are not being respected or taken seriously, that member must bring it to the attention of the team in order for the issue to be resolved. We shall NOT let emotions dictate our actions- everything done is for the benefit of the project and together everyone achieves more.

Ethics

Team members are required to be familiar with the NSPE Engineering Code of Ethics as they are responsible for their obligations to the public, the client, the employer, and the profession. There will be stringent following of the NSPE Engineering Code of Ethics.

Dress Code

Team meetings will be held in casual attire. Sponsor meetings and group presentations will be business casual to formal as decided by the team per the event.

Weekly and biweekly Tasks

Team members will participate in all meetings with the sponsor, advisor and instructor. During said times, ideas, project progress, budget, conflicts, timelines and due dates will be discussed. In addition, tasks will be delegated to team members during these meetings. Repeat absences will not be tolerated.

Decision Making

It is conducted by consensus and majority of the team members. Should ethical/moral reasons be cited for dissenting reason, then the ethics/morals shall be evaluated as a group and the majority will decide on the plan of action. Individuals with conflicts of interest should not participate in decision-making processes but do not need to announce said conflict. It is up to each individual to act ethically and for the interests of the group and the goals of the project. Achieving the goal of the project will be the top priority for each group member. Below are the steps to be followed for each decision-making process:

- Problem Definition – Define the problem and understand it. Discuss among the group.
- Tentative Solutions – Brainstorms possible solutions. Discuss among group most plausible.
- Data/History Gathering and Analyses – Gather necessary data required for implementing Tentative Solution. Re-evaluate Tentative Solution for plausibility and effectiveness.
- Design – Design the Tentative Solution product and construct it. Re-evaluate for plausibility and effectiveness.
- Test and Simulation/Observation – Test design for Tentative Solution and gather data. Re-evaluate for plausibility and effectiveness.

- Final Evaluation – Evaluate the testing phase and determine its level of success. Decide if design can be improved and if time/budget allows for it.

Conflict Resolution

In the event of discord amongst team members the following steps shall be respectfully employed:

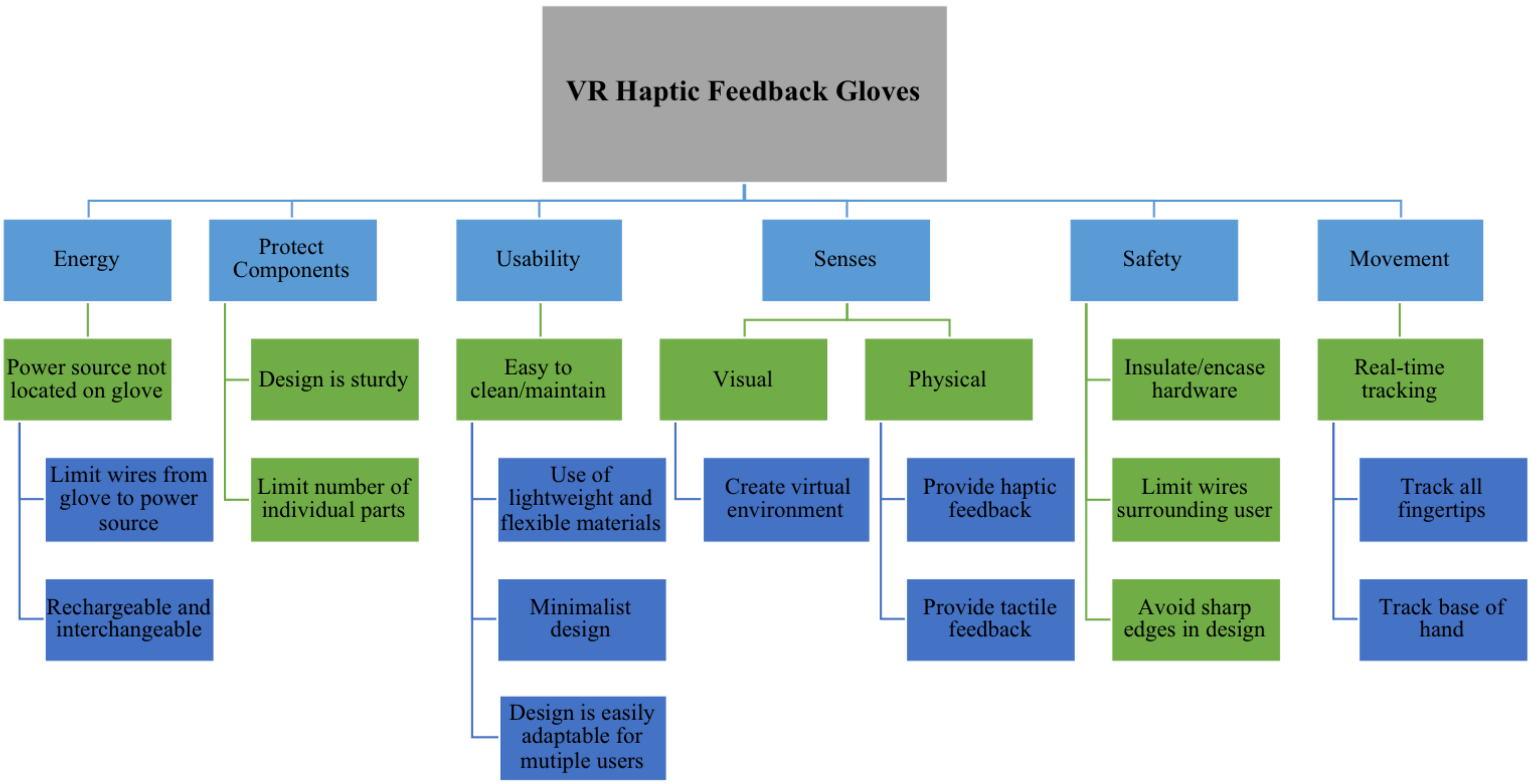
- Communication of points of interest from both parties which may include demonstration of active listening by both parties through paraphrasing or other tool acknowledging clear understanding.
- Administration of a vote, if needed, favoring majority rule.
- Project Manager Intervention.
- Instructor will facilitate the resolution of conflicts.

Statement of Understanding

By signing this document the members of Team 1 agree the all of the above and will abide by the code of conduct set forth by the group.

Name	Signature	Date
____________________________	________________________	_________
____________________________	________________________	_________
____________________________	________________________	_________
____________________________	________________________	_________

Appendix B: Functional Decomposition



Appendix C: Target Catalogue

Metric	Target
Maximum system latency	20 milliseconds
Maximum glove temperature above ambient temperature	5 °Fahrenheit
Battery life per charge	2 hours
Tactile Feedback	Retain real life sensation of touch
Haptic feedback	Physical stimuli in response to VR environment
Durability	withstand drop from 4 feet
Maximum weight per glove	10 ounces
Minimum feedback zones per glove	6
Palm width of glove	4 inches
Maximum glove thickness	1 inch

Appendix D: Pairwise Comparisons for Concept Selection

The tables below are pairwise comparisons done for each subsystem. Costumer requirements are compared against each other to determine which is the most important. These comparisons are used to determine an importance weight factor for each customer requirement associated with a given subsystem. These factors are used in the houses of quality to help refine engineering characteristics.

Pairwise Comparison for Gloves						
Characteristic	**Haptic feedback**	**Tactile feedback**	**Cost**	**Durability**	**Water resistance**	**Total**
Haptic feedback	1	1	9	5	9	25
Tactile Feedback	1	1	5	5	9	0
Cost	0.11	0.2	1	0.2	5	6.51
Durability	0.2	0.2	5	1	9	15.4
Water resistance	0.11	0.11	0.2	0.11	1	1.53

Pairwise Comparison for Tracking					
Characteristic	**Size**	**Accuracy**	**Time**	**Cost**	**Total**
Size	1	5	0.2	9	15.2
Accuracy	0.2	1	0.2	9	10.4
Time	5	5	1	9	20
Cost	0.11	0.11	0.11	1	1.33

Pairwise Comparison for Power Supply				
Characteristic	**Weight**	**Range of Motion**	**Efficiency**	**Total**
Weight	1	5	0.2	6.2
Range of Motion	0.2	1	9	10.2
Efficiency	5	0.11	1	6.11

Pairwise Comparison for Haptic Feedback						
Characteristic	**Characteristic**	**Weight**	**Effectiveness**	**Durability**	**Cost**	**Total**
Weight	1	0.2	0.2	5	1	7.4
Effectiveness	5	1	5	5	1	17
Durabilty	5	0.2	1	9	5	20.2
Cost	0.2	0.2	0.11	1	5	6.51
Size	1	1	0.2	0.2	1	3.4

Pairwise Comparison for Microprocessor					
Characteristic	**Size**	**Cost**	**Processor**	**Memory**	**Total**
Size	1	3	0.5	1	5.5
Cost	0.33	1	0.5	0.5	2.33
Processor	2	2	1	2	7
Memory	1	2	0.5	1	4.5