DESIGN AND FABRICATION OF HAPTIC GLOVE

A Final Year Project Report

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In Partial Fulfillment

of the Requirements for the Degree of

Bachelor of Mechanical Engineering

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ABSTRACT

Haptic feedback gloves offer a solution to the challenges faced by companies in providing hands-on training to operators. Traditional training methods often involve high costs and potential risks in hazardous environments. Haptic gloves provide a wearable device that allows users to experience realistic touch and interactions through advanced feedback within a virtual environment. This technology enables employees to be trained effectively without the need for expensive equipment or exposure to dangerous situations. By incorporating haptic feedback into virtual training scenarios, trainees can feel and interact with virtual objects, leading to improved efficiency, immersion, and skill development. The adoption of haptic gloves in virtual training has the potential to revolutionize employee training, resulting in cost savings, enhanced safety, and increased accessibility. This abstract explores the benefits of using haptic feedback gloves in virtual training and their impact on overall operational performance in various industries.

ORIGINALITY REPORT

The work presented in our Final Year Project (FYP) thesis is original and has been meticulously developed through extensive research and analysis. Our ideas and concepts are the result of independent thinking and have not been copied from any existing work. Throughout the research process, we consulted a wide range of sources, including academic journals, books, and credible online resources, to ensure the originality and validity of our findings.

Our FYP thesis offers a unique perspective on the subject matter, showcasing innovative approaches and insights that have not been previously explored. The conclusions drawn in our thesis are derived from original ideas and critical analysis of the data we collected during our research. To maintain academic integrity and avoid plagiarism, we have appropriately included citations and references throughout our thesis. These citations acknowledge the contributions of other authors and ensure that our work is built upon a solid foundation of existing knowledge while distinctly showcasing our original contributions.

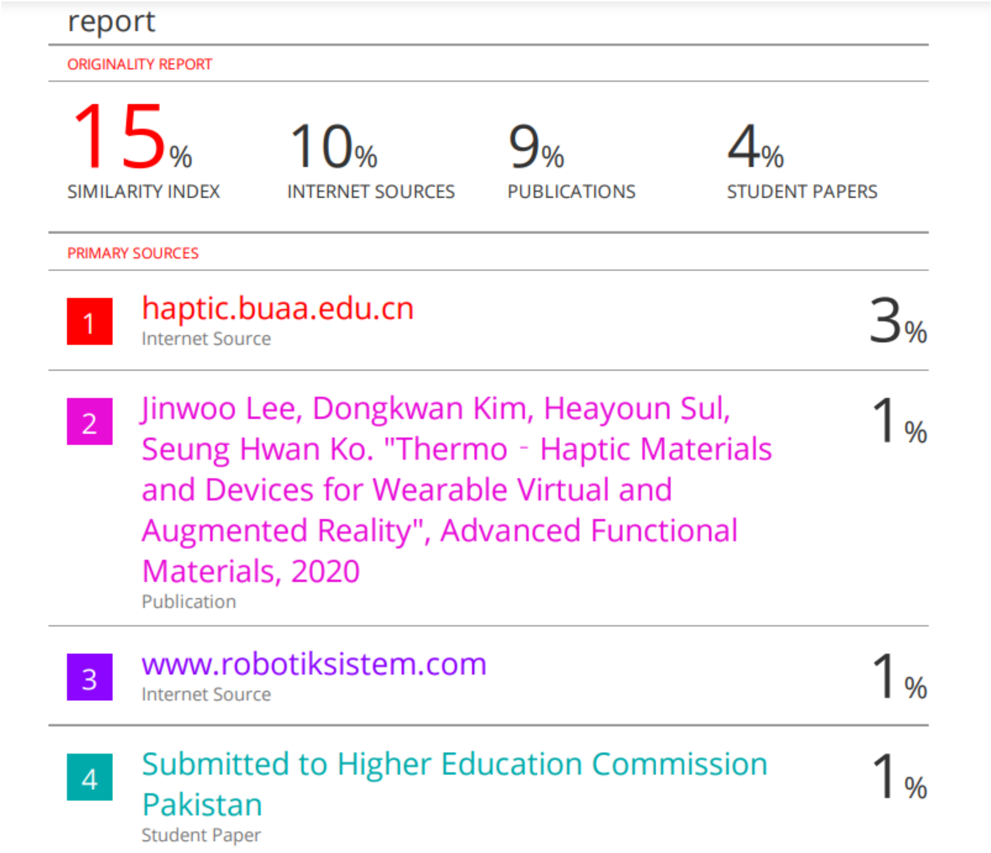

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TABLE OF CONTENTS

INTRODUCTION

1.1 Historical Background:

The concept of virtual reality dates back to the 1930s when science fiction author Stanley G. Weinbaum introduced the idea of a virtual world that people could experience through a pair of goggles in his short story "Pygmalion's Spectacles". In the 1960s, computer scientist Ivan Sutherland created the first head-mounted display system, called "The Sword of Damocles," which could display simple wireframe graphics. In the 1980s, NASA and video game companies began experimenting with VR technology, but it remained expensive and limited in its capabilities. The 1990s saw the release of the first consumer VR systems, but they were unsuccessful due to their high cost and limited capabilities. Recent advancements in computer graphics, display technology, and motion tracking have made VR more immersive and affordable than ever before.

1.2 Conventional Professional Training

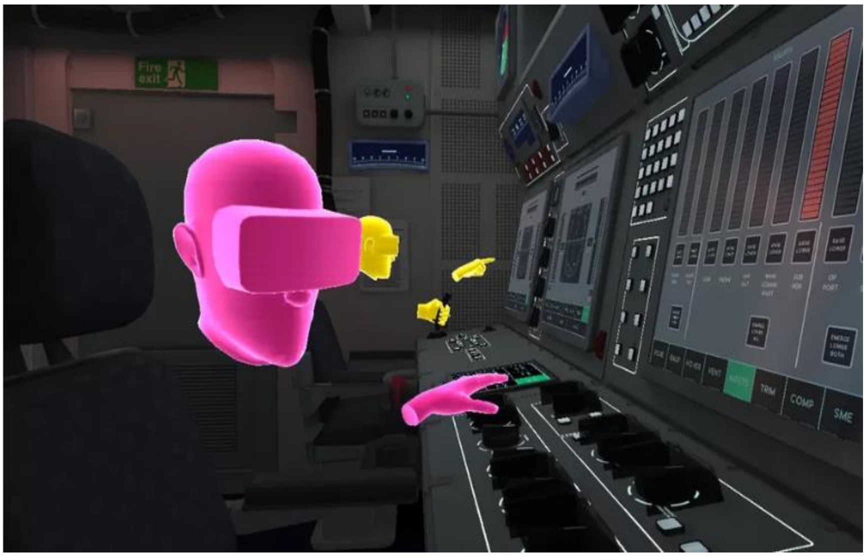
Traditional on-the-job training has limitations in terms of safety, time, and resources. Hands-on training may pose risks to trainees or damage to equipment, which could be expensive and time-consuming to repair. Also, traditional training may not be accessible to individuals in remote locations or those with physical disabilities. In addition, conventional training methods may not provide a realistic environment for trainees to learn and practice. This can limit the effectiveness of the training, leading to poor performance and decreased productivity.

1.3 Virtual Reality (VR)

Virtual Reality (VR) technology has become increasingly popular in recent years, providing users with an immersive three-dimensional environment that can be experienced through various sensory modalities. It has the potential to revolutionize the way we interact with digital content, especially in the field of industrial training. In this report, we will explore the role of haptic gloves in enhancing the VR training experience.

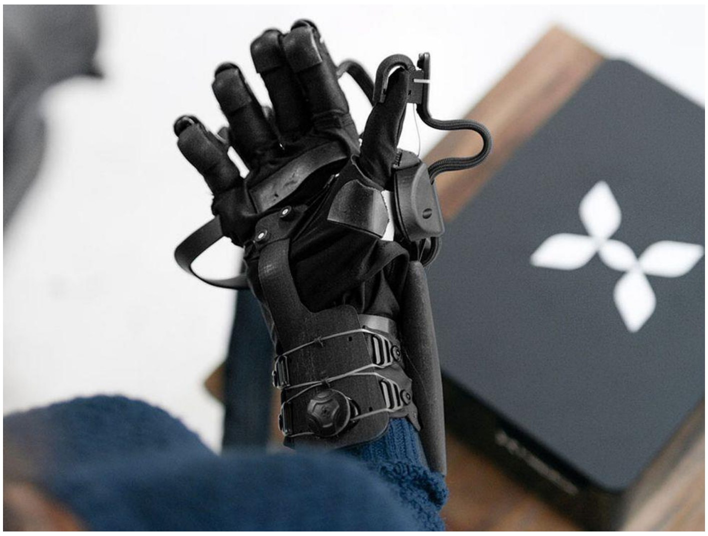
1.4 VR Training

VR training provides a cost-effective industrial training solution to the challenges of traditional training methods. It removes the need for significant investments in infrastructure, equipment, and personnel, making it a more accessible and affordable option for companies. With VR training, employees can be trained remotely, minimizing the risk of accidents, and reducing the need for on-the-job training. VR training also provides a safe and immersive environment for hands-on experience, allowing employees to develop skills more effectively. Additionally, it can simulate a range of real-world scenarios, providing employees with experience in handling various situations, without the cost and risk associated with actual on-site training. Overall, VR training offers a practical solution for industrial training, providing a safe, cost-effective, and accessible means of skill development.



1.5 Haptic Gloves in VR

Haptic gloves are wearable devices that allow users to experience touch sensations in virtual environments. They use sensors, actuators, and software to provide feedback to the user's hands, enhancing the user's sense of immersion and providing a more realistic experience. Haptic gloves are an integral part of VR systems, as they allow users to interact with the virtual world and feel the tactile feedback generated by the virtual environment.



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2 LITERATURE REVIEW

2.1 Force Feedback

Force feedback in haptic gloves refers to the sensation of touch or force that the user experiences while wearing the gloves. Force feedback is an essential aspect of haptic gloves that increases immersion in virtual environments by providing users with a realistic sense of touch and pressure. It is important in perception of gross shape, weight, and impact forces. It is also critical for locomotion – walking, running, etc. When a user interacts with a virtual object using haptic gloves, the gloves use actuators to apply force or resistance to the user's fingers or hand, simulating the sensation of touch and pressure.

This feedback enhances the user's sense of presence and engagement in the virtual environment by providing a more realistic and immersive experience. The user can feel as though they are actually interacting with physical objects, which increases their sense of immersion. Overall, force feedback is a crucial aspect of haptic gloves that enhances the user's sense of immersion in virtual environments by providing a realistic sense of touch and pressure.

2.1.1 Early Development

The development of force feedback in haptic gloves can be traced back to the 1960s, when the first haptic interfaces were developed for use in teleoperation of robotic arms. However, it wasn't until the late 1980s that haptic gloves were developed specifically for human-machine interaction. In 1988, Srinivasan and Basdogan developed the first force-feedback haptic glove, which was capable of providing kinesthetic and cutaneous feedback. The glove used DC motors as actuators and provided forces up to 6 N.

Since then, researchers have continued to investigate different types of actuators and materials suitable for haptic gloves. In the 1990s, researchers began experimenting with pneumatic actuators, like the ones employed in the Rutgers Master II haptic glove, a collaborative effort by Colgate and Brown. This particular glove utilized pneumatic balloon actuators and air jet nozzles to deliver kinesthetic feedback to four fingers and cutaneous feedback to two finger pads.

During the early 2000s, researchers delved into exploring alternative active actuators for haptic gloves, including shape memory alloys, electro-active polymers, and artificial muscles.

More recently, there has been a growing interest in employing soft robotic technology for haptic feedback. Soft robots, constructed from varying grades of silicone material, incorporate pneumatic channels. These robots achieve actuated motion through pneumatics, and the soft and pneumatic nature of the actuators enables the creation of lightweight and safe interfaces for human-machine interaction. In 2015, Polygerinos et al. developed a 5-finger soft robotic glove actuated by hydraulic multi-segment soft actuators. This glove allowed for 1 active degree of freedom for each finger and weighed 285g.Advancements in technology, particularly in the field of robotics, enabled the development of more sophisticated force feedback mechanisms. Haptic gloves began to incorporate more advanced sensors and actuators, such as force sensors and motors, which could provide users with a more realistic sense of touch and pressure.

In recent years, the development of flexible, soft-wearable devices has further improved the force feedback capabilities of haptic gloves. These devices can conform to the human form factor with minimal loss of accuracy, and they can replicate the sensation of touch and pressure with greater precision than ever before.

Overall, the development of force feedback in haptic gloves has been a gradual process that has improved over time with the advancement of technology. Today's haptic gloves are capable of providing users with a more realistic and immersive experience than ever before, thanks to advancements in sensors, actuators, and materials.

2.1.2 Design Challenges of Force Feedback Gloves

The performance of a force feedback glove can be evaluated based on several metrics.

- **Back drivability**

One such metric is *back drivability*, which refers to the ability to simulate free space without the presence of friction and inertial force exceeding the human's ability to detect force magnitude.

The principle of back drivability in haptic technology is based on the requirement that free space must be unrestricted. This principle can be measured using the metric of back drivability, which refers to the amount of friction and inertial force present in the simulation. For the simulation to be effective, these forces should be lower than the human threshold for detecting force magnitude.

- **Achievable stiffness**

An additional crucial aspect to consider is the attainable stiffness, which plays a significant role in simulating restricted spaces and encompasses the highest level of stiffness that can be achieved on the fingertip to replicate the sensation of touching a solid object. In order to accomplish this, an essential metric for simulating confined environments involves determining the maximum attainable stiffness of the virtual object. This implies that the stiffness equivalent experienced on the fingertip must be sufficiently elevated to effectively simulate the sensation of interacting with a rigid object.

- **Force Control Error**

The haptic glove should exhibit a minimal force control error to enable users to accurately detect changes in force. The force control error needs to be smaller than the discrimination threshold for force perception, typically ranging between 7-10% over a force range of 0.5-200 N. Put simply, the haptic glove must possess a precise force control capability on the user's hand, allowing them to differentiate between different force levels with an error rate of less than 10%. This level of precision is crucial for ensuring a realistic and immersive user experience with the haptic glove.

- **Wearability**

To develop a force-feedback glove with exceptional performance, several key performance metrics must be considered. These metrics include wearability, the method of glove attachment to the hand, force and torque transmission to the fingers, and adaptability to different hand sizes. Wearability is influenced by factors such as the form factor, weight, shape, area of focus, and ergonomic design of the haptic interface. Furthermore, the glove should be comfortable to wear, easy to put on and remove to prevent user fatigue. It is essential for the glove to be lightweight, even with the inclusion of its battery and controller. Safety is also paramount, ensuring that the glove does not pose any risk of injury to the user, even in the event of system failures.

Despite over two decades of research on force feedback gloves, achieving comprehensive haptic sensations encompassing force, tactile, and thermal feedback for the entire hand remains a significant challenge. This challenge stems from the dense concentration of mechanoreceptors within the limited surface area of the human hand, as well as the intricate multi-degree-of-freedom capabilities required for dexterous finger manipulation. In future virtual reality contexts, creating realistic haptic sensations on users' hands will be crucial for achieving complete immersion, interaction, and imagination within the virtual reality experience. Overcoming these challenges may rely on the development of innovative, interdisciplinary solutions combining material science, robotics, and a comprehensive understanding of the biology and psychology of the human haptic system.

2.1.3 Classification on the basis of type of feedback

- **Passive Feedback**

There are different approaches to actuation in haptic gloves, including resistive devices and active devices. Resistive devices utilize brakes to restrict a user's motion, while active devices employ motors to actively constrain and move the user's body. In passive actuation, mechanisms like brakes, controllable dampers, or electromagnetic clutches are used to generate resistance forces. These passive actuators offer easy torque control as the forces are directly proportional to the current or magnetic field that activates the coil or damper. One significant advantage of passive actuators is their ability to ensure user safety even in the event of system malfunction. However, they are unable to provide force feedback when the user's hand is stationary.

Passive actuation solutions can employ magnetorheological fluids (MRFs) or clutches to generate resistance forces. MRFs consist of ferromagnetic powder suspended in silicone oil and can form chains of iron particles when a magnetic field is applied, inducing yield stress. A force feedback glove was developed using compact MR brakes placed on the back of the fingers. Clutches and springs have also been utilized in a multifigured force feedback glove, where the applied forces on the user's fingertips are determined by the deflection in the links and the springs at the joints of the finger mechanisms. Another approach involved a passive force display glove (PFDG) that employed electromagnetic on/off brakes. A brake-based locking sliders mechanism was proposed to provide directional braking using the concept of Active Brake Engagement, capable of withstanding forces of over 100 N between each finger and the thumb. Similarly, Dexmo is a lightweight and safe mechanical exoskeleton that offers binary haptic feedback. Zubrycki et al. developed a haptic glove utilizing the jamming principle, where a granular material enclosed in flexible membranes transitions from a liquid-like state to a solid-like state with a small change in volume. They presented two concepts employing either jamming tubes or pads to simulate grasping and exploration tasks. Their design can resist forces up to 7 N with 5 mm displacement when a micro vacuum pump is used as a vacuum source.

- **Active Feedback**

  Active force feedback gloves have the benefit of offering both active motion and generating resistance forces or torques. These gloves make use of active actuators, with DC servo motors being the frequently utilized choice. In order to transmit the torque to the fingertip, a transmission system is usually necessary. Active devices enable a broader range of interaction simulations compared to passive devices, but they can be more powerful and pose challenges in terms of operation.

2.1.4 Classification on the basis of structure of glove

To categorize force-feedback gloves, a classification method based on the actuation location, or the base frame of the gloves is utilized. This method offers two advantages. Firstly, it is straightforward to comprehend and results in four distinct subcategories: ground-based, dorsal-based, palm-based, and digit-based gloves. Secondly, the actuation location significantly affects the magnitude and precision of the feedback force, as well as the weight and size of the glove. Achieving high force output necessitates the use of large motors or high transmission ratios, which can result in either a bulky glove or compromised force accuracy due to increased friction in the transmission system. To strike a balance between these key parameters, various solutions have been proposed, exploring different actuation locations and transmission types.

Ground-Based Systems

Ground-based systems are characterized by having a fixed base on the ground or desk. One example of such a system is the HIRO III, comprising a 6-DoF robotic arm and a five-fingered haptic hand. Each finger of the haptic hand possesses 3 DoFs, enabling force feedback at the fingertips. The user's hand is connected to the robotic hand using finger holders and passive spherical magnetic joints. The HIRO III system provides high force output and a wide range of force directions, allowing for the replication of weight sensations of virtual objects. However, it has a relatively small workspace compared to body-based systems and certain gesture limitations due to potential interference between the user's fingers and the robotic hand.

Another instance is the SPIDAR-MF developed by Liu et al., which serves as a multi-finger haptic interface. It employs 20 cables to transmit torque from grounded motors to the five fingertip caps. This system has the capability to convey a 3 DoF spatial force on each fingertip of the human hand using 4 cables. Additionally, it can simulate weight sensations of virtual objects during grasping manipulation.

While ground-based systems enable the simulation of force feedback at the fingertips and the perception of external forces like weight sensations and virtual object collisions, they tend to be bulky and less suitable for wearable and mobile applications.

Ground-based


HIRO III, 2009 [18]


SPIDARMF,2014 [19]


HGlove,2017 [48]

Dorsal-Based Systems

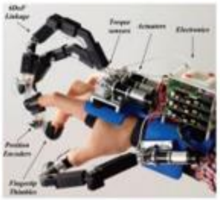
The next category of haptic gloves is wearable exoskeleton systems that are anchored to the back of the hand. One example is a string-based glove created at the University of Tsukuba, which delivers feedback forces of up to 7 N to the index finger and thumb. Another string-based glove, known as the Laboratoire de Robotique de Paris (LRP) hand master, provides feedback forces of up to 14 N to all fingers. The CyberGrasp, a commercial force feedback glove introduced in 1998, is capable of applying a pushing force of up to 12 N to each fingertip. Additionally, various other dorsal-based force-feedback gloves have been developed utilizing different solutions such as passive spring and clutch mechanisms, wire-driven systems, magnetorheological fluid systems, and micro hydraulic systems. Dorsal-based gloves offer the advantage of simulating force feedback at the fingertips in wearable and mobile scenarios. However, they have limitations in simulating weight sensations and presenting three-dimensional forces to the users' fingertips. To address these limitations, innovative transmission mechanisms like the serial link mechanism employed by Koyama et al. and Frisoli et al., as well as the hand exoskeleton developed by Iqbal et al., are currently being explored.

Dorsal-based

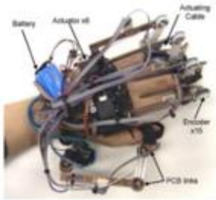

CyberGrasp,1999 [23]


MR glove,2009 [28]


WHE,2014[46]



HEXOTRAC, 2015 [47]



SAFE,2015 [5]

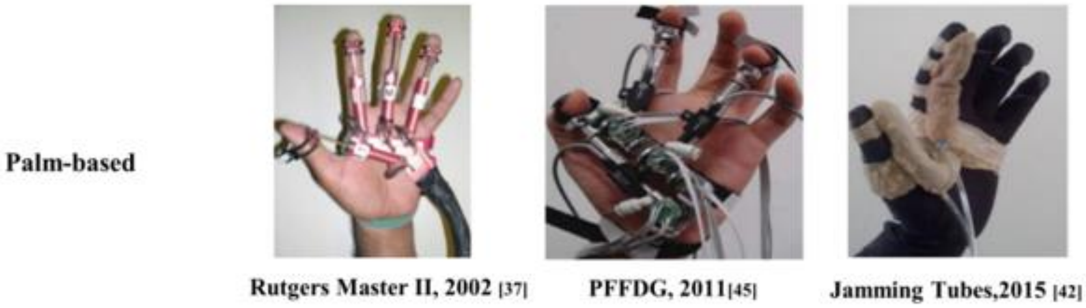

Dexmo,2016 [39]

Palm-Based Systems

To address the size and weight concerns of haptic gloves, researchers have focused on developing methods to transmit force directly from the fingers to the palm, mimicking grasping with palm opposition. These glove systems are connected to the user's palm.

An example of such a system is the Rutgers Master II—New Design (RMII-ND). It incorporates linear pneumatic pistons distributed throughout the palm, directly attached to the fingers. These pistons have the capability to deliver up to 16 N of force to each fingertip. Graphite-on-glass construction of the pistons helps reduce static forces when the glove is not powered. However, the presence of these pistons restricts finger movements, and the compressor adds weight to the device, thereby limiting the available workspace.

In recent research, scientists such as Zubrycki et al. and Simon et al. have explored the application of particle jamming. This technique involves utilizing tubes and wires that traverse along the fingers, creating resistance between the fingers and the palm. By implementing particle jamming, these researchers aim to achieve a smaller overall size and reduce the weight of haptic gloves.



Digit-Based Systems

The fourth category of haptic devices focuses on generating forces between the fingers and thumb to simulate pad opposition or precision grips. These devices are anchored to the digits, specifically the fingers and thumb.

An example of such a device is the DESR glove developed by Zhang et al. It utilizes electroactive polymer actuators to generate forces between the thumb and forefingers. The DESR glove is lightweight but does impose some limitations on finger motion.

For simulating pad opposition grasps, Choi et al. designed a lightweight device that creates forces between the thumb and three fingers. This is accomplished using brake-based locking sliders capable of withstanding forces exceeding 100 N. While this device allows for a wide range of motion and provides high resistance forces, it lacks the ability to simulate variable stiffness.

In summary, these devices aim to replicate the forces experienced during pad opposition or precision grips by generating specific forces between the fingers and thumb, thereby enhancing the haptic feedback experience.

Digit-based

DESR,2006 [40]

Wolverine,2016 [38]

2.1.5 Drawbacks of Traditional Force Feedback System for Haptics

While traditional mechanical force feedback that relies upon motors has been used for many years and is still commonly used, there are some drawbacks to this technology. Here are a few:

1. **Limited resolution**: Motors can produce vibrations or forces, but their resolution is limited. This means that they can't produce very fine or precise sensations. This can be a limitation in some applications where high precision haptic feedback is required.
2. **Limited range of sensations**: Motors can produce vibrations or forces, but they are limited in the range of sensations they can produce. For example, they may not be able to produce temperature or texture sensations, which can be important in some applications.
3. **High power consumption**: Motors require a lot of power to operate. This can be a limitation in battery-powered devices where power consumption is an important consideration.
4. **Noise**: Motors can be noisy in operation, which can be a concern in applications where noise is a problem, such as in a quiet laboratory or medical setting.
5. **Large form factor**: Motors can be relatively large and bulky, which can be a limitation in applications where space is at a premium, such as in a small medical device or wearable technology.
6. **Maintenance**: Motors have moving parts, which can wear out over time and require maintenance or replacement. This can be a limitation in applications where reliability and long-term maintenance costs are a concern.

Overall, while traditional mechanical force feedback that relies upon motors has been widely used and can be effective in many applications, it does have some limitations and drawbacks that may make it unsuitable for certain applications or situations.

Latest development in Force Feedback System for Haptics

2.1.6 Latest development in Force Feedback System for Haptics

Pneumatic based Systems

An additional type of actuator commonly used in haptic gloves is the pneumatic actuator. This actuator employs pneumatic balloon actuators and air jet nozzles to deliver haptic feedback to four fingers and cutaneous feedback to two finger pads. It offers a unique method of providing feedback through the use of air pressure.

Other options for active actuators in haptic gloves include Shape Memory Alloys (SMAs), electro-active polymers, and artificial muscles. These materials can be utilized to create actuators that enable active control and simulate force and motion output with a high update rate. However, one drawback of active actuation is the potential risk of finger injury in the event of a system failure. To mitigate this risk, most active gloves implement safety measures by limiting the maximum output force to approximately 10 N. This ensures that the force applied to the user's fingers remains within a safe range, minimizing the risk of injury.

In summary, pneumatic actuators and other active actuation methods provide haptic feedback in haptic gloves by actively controlling force and motion. While they offer advantages such as high update rates and active control, safety measures are necessary to prevent potential finger injuries during system failures.

Soft robotic technology

In recent times, there has been a growing interest in exploring the application of soft robotic technology for haptic feedback. Soft robots are constructed using silicone material and incorporate pneumatic channels, enabling them to serve as safe interfaces for human-machine interaction. Researchers have developed a fabric-based soft tactile actuator and sensor, which utilizes a multi-layer composition of paper and fabric. This tactile actuator features air channels and an actuation site, capable of generating sufficient forces to induce haptic perception at the fingertip. The thin and sheet-like nature of the material used in these soft actuators opens up possibilities for the development of compact and lightweight gloves.

One notable advancement in this field is the work by Polygerinos et al., who introduced a soft robotic glove with five fingers. This glove utilizes hydraulic multi-segment soft actuators positioned on the dorsal side of the hand, effectively avoiding potential interference between the actuators and the fingers. The design of the glove enables it to replicate finger and thumb motions required for typical grasping movements. Each finger is endowed with one active degree of freedom, providing enhanced dexterity. Remarkably, this soft robotic glove weighs only 285 grams, contributing to its overall usability and wearability.

Microfluidics

In recent years, microfluidics has emerged as a promising approach for haptic feedback in haptic gloves. Microfluidics refers to the study and manipulation of fluids at the microscale, typically in channels and chambers with dimensions ranging from a few micrometers to hundreds of micrometers. The use of microfluidics in haptic feedback offers several advantages over conventional approaches.

Here are a few reasons why microfluidic haptic feedback may be considered better:

1. *Higher resolution:* Microfluidic haptic feedback allows for much finer control over the forces applied to the user's skin. This is because the fluid channels can be

designed to produce very precise patterns of pressure, allowing for much higher resolution than traditional motors.

2. *Quieter operation:* Since microfluidic haptic feedback does not rely on motors, it can be much quieter in operation. This makes it ideal for applications where noise is a concern, such as in a quiet laboratory or medical setting.
3. *Smaller form factor:* Microfluidic haptic feedback can be designed to be much smaller than traditional motors. This makes it ideal for applications where space is at a premium, such as in a small medical device or wearable technology.
4. *Reduced power consumption:* Microfluidic haptic feedback requires less power than traditional motors. This can be an important consideration in battery-powered devices, where every bit of power saved can extend the battery life.
5. *More versatile:* Microfluidic haptic feedback can be designed to produce a wide range of different sensations, including pressure, temperature, and even texture. This makes it more versatile than traditional mechanical force feedback, which is typically limited to producing simple vibrations or forces.

Overall, microfluidic haptic feedback offers a number of advantages over traditional mechanical force feedback. While it may not be suitable for every application, it is an exciting new technology that is opening up new possibilities for haptic feedback in a wide range of fields.

Development of Microfluidic Technology for Haptics

The idea of using microfluidics for haptic feedback was first proposed in 2010 by researchers at the University of Bristol in the UK. They developed a haptic device based on a microfluidic platform that used water as the working fluid. The device consisted of a thin, flexible membrane that was coated with a layer of silicone rubber. The membrane was placed between two layers of microfluidic channels, which were connected to a pump that generated pressure variations in the channels. When a user pressed on the membrane, the pressure variations in the channels generated a force that was transmitted to the user's fingertip.

Since then, several research groups have explored the use of microfluidics for haptic feedback in haptic gloves. In 2013, researchers at the University of Tokyo developed a haptic glove that used microfluidic channels to provide tactile feedback to the fingertips. The glove consisted of a flexible membrane that was coated with a layer of silicone rubber, and a set of microfluidic channels that were embedded in the membrane. The channels were connected to a pump that generated pressure variations in the channels, which were transmitted to the user's fingertips. The researchers demonstrated that the glove was capable of providing a wide range of tactile sensations, including pressure, vibration, and texture.

In 2015, researchers at the University of British Columbia in Canada developed a haptic glove that used microfluidic channels to provide thermal feedback to the fingertips. The glove consisted of a flexible membrane that was coated with a layer of silicone rubber, and a set of microfluidic channels that were embedded in the membrane. The channels were filled with a thermally conductive fluid, such as water or glycerol, and were connected to a heating or cooling source. When a user touched an object, the temperature of the fluid in the channels changed, which generated a thermal sensation that was transmitted to the user's fingertips.

More recently, researchers at the University of California, Los Angeles (UCLA) have developed a haptic glove that uses microfluidic channels to provide tactile feedback to the fingertips. The glove consists of a flexible membrane that is coated with a layer of silicone rubber, and a set of microfluidic channels that are embedded in the membrane. The channels are filled with a fluid that can change its viscosity in response to an applied voltage, such as an electrolyte solution. When a user touches an object, an electrical signal is applied to the channels, which causes the fluid to change its viscosity and generate a tactile sensation that is transmitted to the user's fingertips.

The use of microfluidics in haptic feedback offers several advantages over conventional approaches. For example, microfluidic channels can be integrated into flexible materials, such as silicone rubber or fabric, which allows for the development of lightweight and flexible haptic gloves. Microfluidic channels also offer precise control of fluid flow, which allows for the generation of complex tactile sensations, such as texture and shape. Additionally, microfluidics is a low-power technology, which makes it suitable for portable and wearable applications.

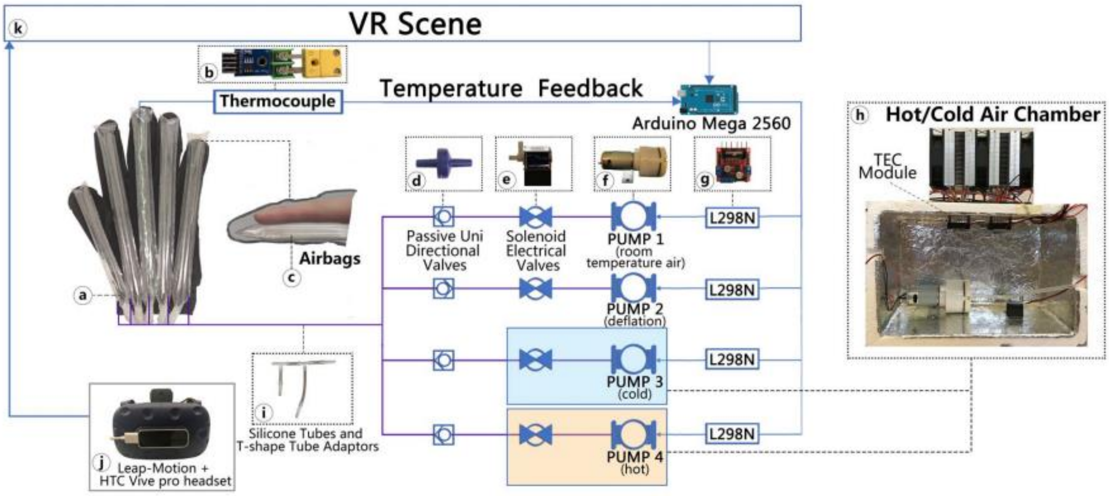
2.2 Thermal Feedback

A lot of research has been done in the visual and auditory feedback in virtual reality. The ability to replicate tactile perceptions including pressure, touch, discomfort, itching, and temperature has made relatively little progress in contrast.

Thermal sensation, one of the tactile senses associated with the human skin, plays the most significant role because of the constant heat exchange with other thermal entities via physical contact. In addition to simple temperature sensing, objects with different thermal conductivities, even at the same temperature can be differentiated by the human body via touch. If we can simulate the thermal properties of materials in VR, it would increase the immersion considerably. Although there are a lot of techniques to implement thermal feedback, we discuss three mains in this literature review.

2.2.1 Pneumatic Thermal Feedback

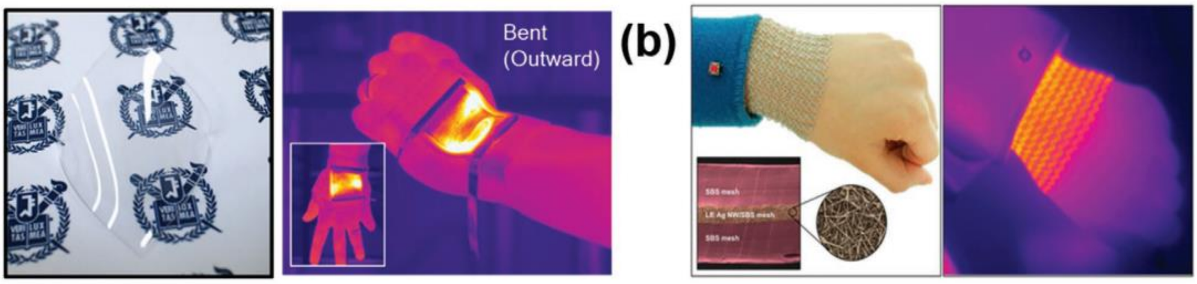
The thermal feedback can be provided using air as discussed in [1]. In this system This system comprises of a glove with inflatable airbags attached to the fingers and palm, two temperature chambers, and a control system for both pneumatic and thermal functions. By blending the air from room temperature with the air from the hot and cold chambers, the system is capable of generating thermal signals with varying degrees of intensity. This can increase the immersion in VR, but it makes the glove very bulky. Plus, the response in this sort of system is very slow.



2.2.2 Joule Heating

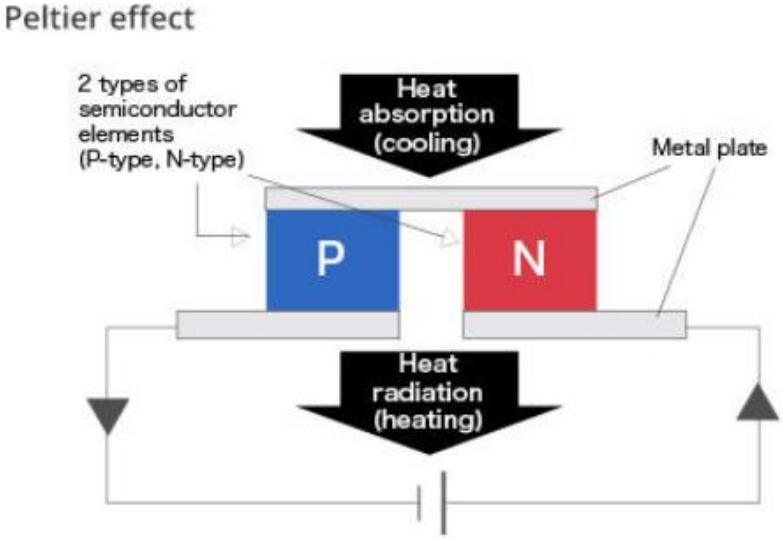
When current flows through an electrode, some of the kinetic energy from the electrons is converted into heat, thus heating the electrode. In this way flexible electrodes can used as wearable thermal feedback devices in VR. Over the last twenty years, significant advancements have been made in flexible and stretchable electrodes, which have enabled the creation of precise, effective, durable, and feasible thermos-haptic devices that rely on Joule heating. [2]

Therefore, wearable heaters can only serve a purpose in a THD if they are utilized alongside cooling apparatuses. This is because, in the absence of a cooling system, these heaters are unable to generate a temperature lower than that of the surrounding room.



2.2.3 Thermoelectric Devices

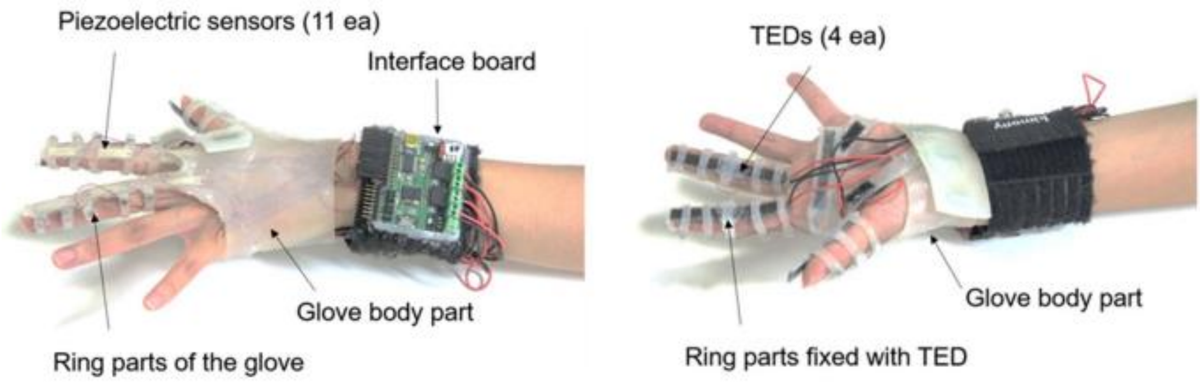
The thermoelectric (TE) effect is a physical mechanism that enables the heating and cooling of the human skin surface through heat conduction. Also known as the Peltier effect, it involves the movement of charge carriers in a p- or n-type semiconductor towards one junction when an electrical voltage is applied to the system. As a result, the end of the device with a higher density of charge carriers heats up, while the other end cools down. Reversing the direction of the electrical current causes the opposite effect. By adjusting the electrical current, the device's temperature can be actively controlled, making it possible to achieve the desired temperature in a thermo-haptic system that may be higher or lower than room temperature.[2]



2.2.4 Flexible Thermoelectric Devices

Conventional TEDs are designed with a stiff substrate like a dielectric ceramic plate, which poses limitations for use in glove-type devices that require frequent hand bending and finger unfolding. In light of this, research has focused on developing flexible TEDs that can adapt to different geometrical forms.

A thermal display glove that is fully untethered and can interact with a VR environment in real-time is introduced in [3]. The system is lightweight and untethered, which improves its wearability and allows for free movement in any posture. Moreover, the glove is equipped with a flexible TED that can display a broad range of temperatures within a few seconds, enabling the user to experience various thermal sensations in the VR environment as if in real life.



2.3 Tactile Feedback

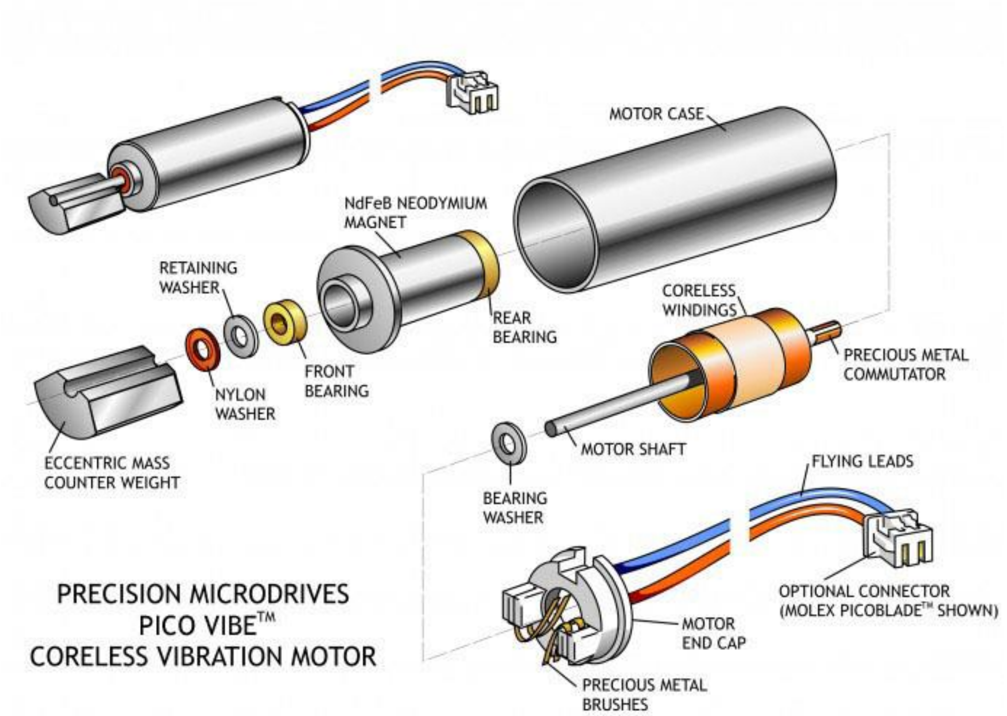
When a user's hand comes into contact with an interactive object, the haptic glove plays a crucial role in providing tactile feedback to simulate the sensation of touch. This feedback is achieved through the utilization of actuators and vibration motors that are integrated into the glove.

The specific vibrations used for haptic feedback are generated using one of two types of actuators: Eccentric Rotating Mass (ERM) Motors or Linear Resonant Actuators (LRA). In our case, we have opted to use ERM motors due to their widespread availability and ease of implementation. In the following section, we will delve into a detailed discussion of ERM motors and explore the methods for effectively controlling them within haptic gloves.

2.3.1 Eccentric Rotating Mass (ERM) Motor

The Eccentric Rotating Mass (ERM) vibration motor is known for its simplicity in design. These motors are available in cylindrical or coin-shaped forms, often referred to as "pager motors." The ERM motor operates by rotating an unbalanced weight around the motor shaft, creating centripetal force that causes the motor to vibrate when repeated. These motors are typically based on DC motor technology, making them easy to drive and requiring only a DC voltage source with sufficient current capacity.

While ERM motors are commonly used for vibration alerting purposes, they can also be utilized for haptic feedback when combined with a suitable processor driver IC. By adjusting the speed of the motor, the haptics processor or driver can modify the vibration amplitude and frequency, allowing for the generation of different haptic sensations.



CONTROLLING VIBRATION AMPLITUDE

It is important to acknowledge that the measurement of vibration amplitude in a controlled laboratory environment does not fully reflect the real-world perception of vibration due to various factors, including:

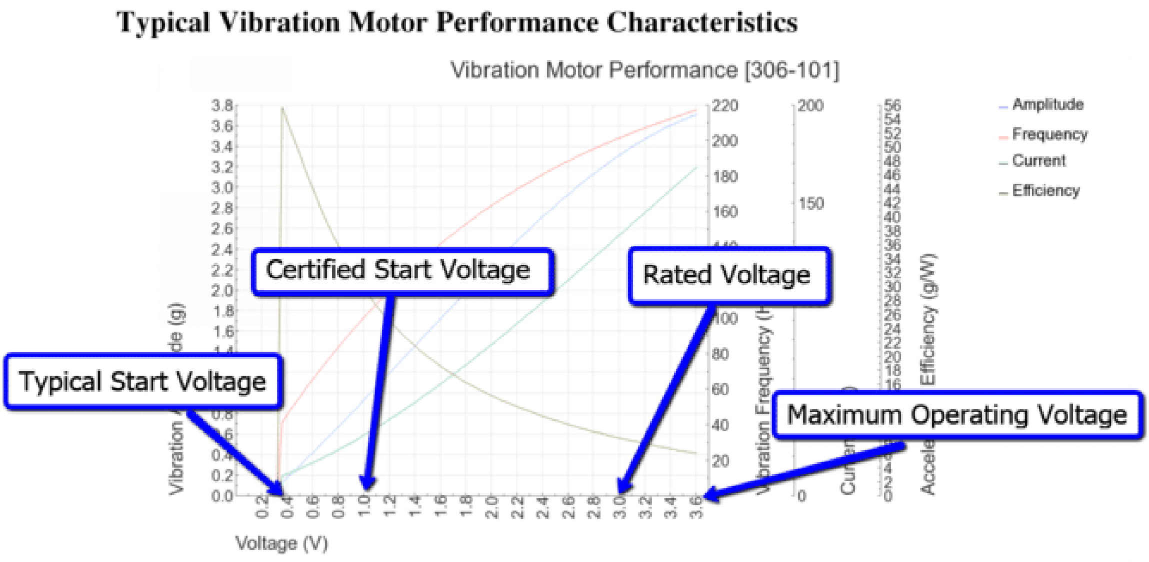
- Rigidity or flexibility of the device
- Motor orientation
- Weight of the device
- User age
- Position of the device on the body
- Vibration frequency
- Environmental factors

Different applications have distinct requirements for vibration amplitude. For example, a small wearable device intended for children would necessitate lower vibration intensity compared to an industrial hopper. By adjusting the vibration intensity, it becomes possible to create advanced haptic effects, which is an exciting and rapidly growing field. By varying the intensity and pattern of vibration, an extensive range of combinations, rhythms, or messages can be achieved. Industries such as wearables and automotive are particularly embracing this technology.

CONTROLLING SPEED

Controlling the motor speed in ERM actuators can be achieved by adjusting the driving voltage. By increasing the voltage applied to the motor, it is capable of generating more torque. Since the load on the motor is fixed, the rotational speed increases as a result.

To ensure reliable and consistent motor operation, it is important to consider the recommended driving voltage range specified by two key parameters. The first parameter is the Maximum Start Voltage, which defines the minimum voltage required to initiate motor operation. Although it may seem counterintuitive to use a "Maximum" value to define the minimum voltage, this specification is used to ensure that the motor starts reliably. While it is possible for the motor to operate below this voltage, there is no guarantee of reliable performance in such cases. Therefore, it is recommended to provide a voltage equal to or higher than the specified Maximum Start Voltage to ensure consistent motor operation.



4 Important Voltages for Vibration Motors

To avoid damaging the motor, it is crucial to not exceed the Maximum Rated Operating Voltage, which represents the upper limit of the voltage that should be applied to the motor. Operating the motor beyond this limit can lead to damage. It is also recommended not to exceed the Rated Voltage for an extended period of time, as doing so can accelerate brush wear and reduce the motor's lifespan. Values such as Maximum Operating Current may not be accurate when the motor is driven above the rated voltage.

Detailed specifications including the Maximum Rated Operating Voltage, Rated Voltage, and other relevant information can be found in the product data sheets.

Various methods can be employed to alter the applied voltage, depending on the circuit and application. The most common approach is to use Pulse Width Modulation (PWM) control, which allows for precise voltage adjustment. Other methods include using a basic linear voltage divider or dedicated motor drivers. Some motor drivers, such as the DRV2605, come with built-in libraries of waveforms (e.g., clicks and ramp-ups) that handle the drive voltage automatically.

In cases where an unregulated power source like a battery is used, the driving voltage typically decreases as the battery discharges, resulting in a drop in motor speed.

For Brushless DC vibration motors, the method of changing the speed depends on the specific driver being used. For example, the 910-101 motor has an integrated driver that accepts a varying voltage but does not work with PWM. On the other hand, the M10-400 evaluation board utilizes the DRV11873 driver, which does accept a PWM signal.

3 METHODOLOGY

3.1 Sensing Mechanism

To provide force feedback our haptics glove needs a number of sensors that can detect the position, orientation, and movement of the user's hands. We will call location and orientation of hand in real world or 3D environment **Pose** and orientation of fingers **Curl**. In other words, we need to calculate the Pose and Curl of our hand to properly track and render our hands in Virtual Reality environment.

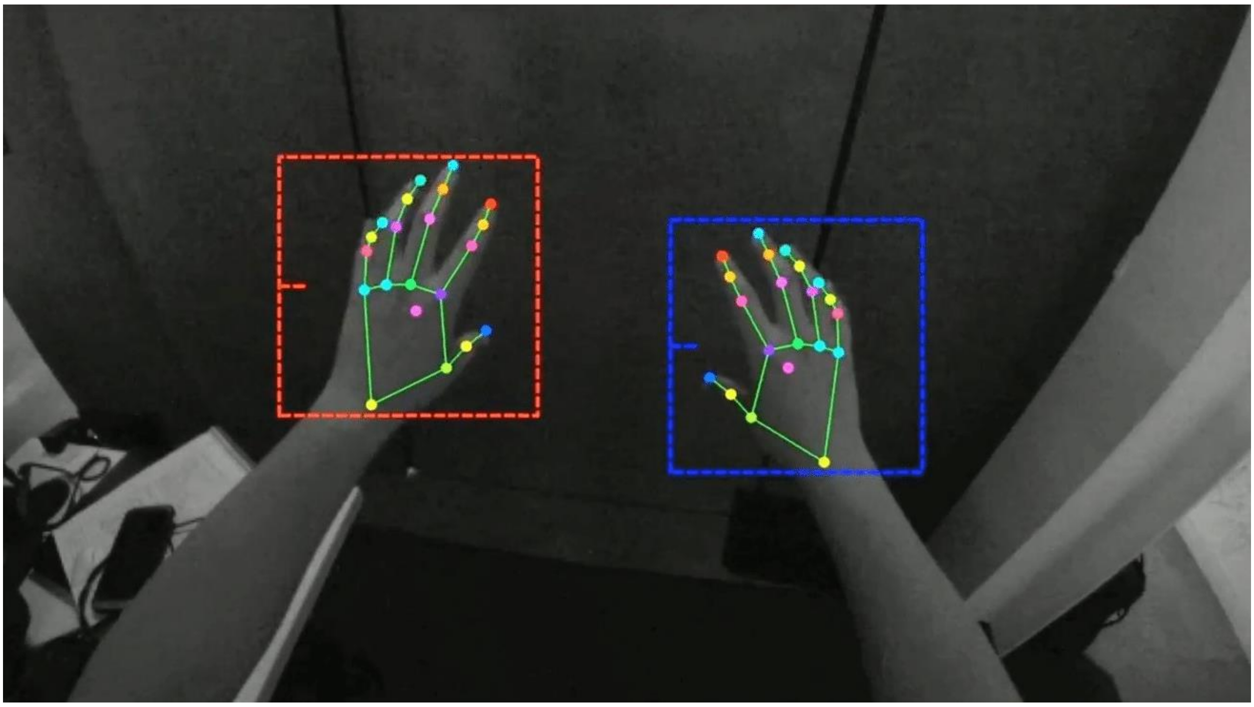
Fortunately, pose tracking is a built-in feature of Oculus Quest headset. For curl tracking we are using a thread wound around a spool-potentiometer configuration.

3.1.1 Pose tracking

The hand tracking system in Oculus Quest 2 uses a combination of machine learning, computer vision, and sensor data to accurately track the position, orientation, and movement of the user's hands in 3D space. Here's a more detailed breakdown of the different components and how they work together:

- *Cameras*: The Oculus Quest 2 has four monochrome cameras built into the device, two on the front and one on each side. These cameras are used to capture images of the user's hands from different angles, allowing the system to create a 3D model of the user's hand movements.
- *Sensor Data:* In addition to the camera images, the hand tracking system also uses sensor data from the device's built-in IMU (Inertial Measurement Unit). The IMU includes sensors such as accelerometers and gyroscopes that provide information on the device's position and movement in space.
- *Computer Vision:* Once the camera images and sensor data are collected, the hand tracking system uses computer vision algorithms to process the data and create a 3D model of the user's hands. The system identifies key features in the hand images, such as the location of fingertips and the shape of the hand and uses this information to create a 3D model of the user's hands.
- *Machine Learning:* To improve the accuracy and robustness of the hand tracking system, Oculus Quest 2 uses machine learning algorithms that have been trained on large datasets of hand images and movements. These algorithms can recognize and track a wide range of hand poses and movements, including finger movements and hand gestures.
- *Hand Gesture Recognition:* Once the system has created a 3D model of the user's hands, it can recognize and interpret hand gestures and movements. The hand tracking system can recognize a variety of hand gestures, such as pointing, grasping, and waving, and use them to interact with virtual objects and interfaces.

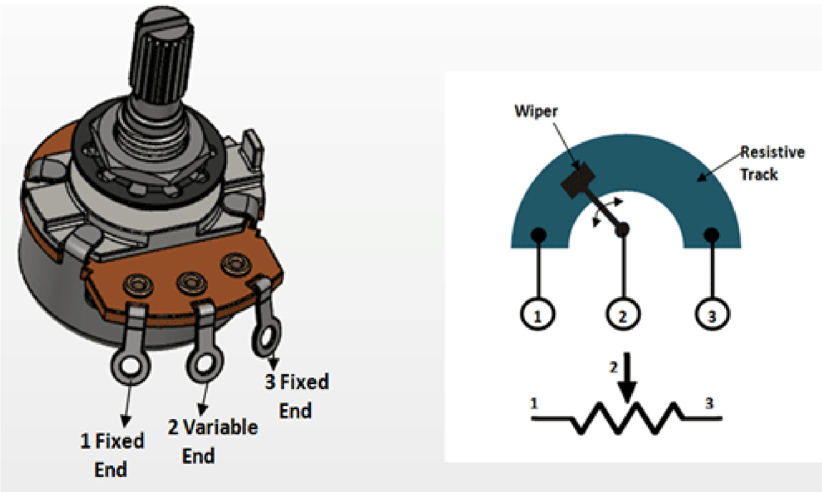
It's worth noting that hand tracking is still an evolving technology, and there may be limitations to its accuracy and responsiveness in certain situations. However, it represents a promising new direction for VR interaction and user experience.



3.1.2 Curl tracking

For curl tracking we are using simple spool-potentiometer configuration. A potentiometer consists of a resistive element and a sliding contact called a wiper; in our case we will be using a potentiometer with a knob. The resistance of the potentiometer changes when the knob is rotated as wiper is moved along the resistive element.

We are using this potentiometer to measure curl, as shown in the image below the knob of potentiometer is fixed in the middle of spool with the help of a screw. A string of wire is wound around the spool. For fingers this thread passes through tree guide notes glued to the gloves at three phalanges (the distal, middle, and proximal). For thumb, there are only two guide notes. As guide notes are attached to fingers, curling them will rotate the knob of potentiometer. As the finger curls, the knob's position on the resistive element changes, causing the resistance of the potentiometer to vary.



To calculate the curl, we can use the voltage divider formula, which states that the voltage across a resistor in a series circuit is proportional to the resistance of that resistor. In the case of a potentiometer, the voltage across the knob and one end of the resistive element will vary depending on the position of the knob along the resistive element.

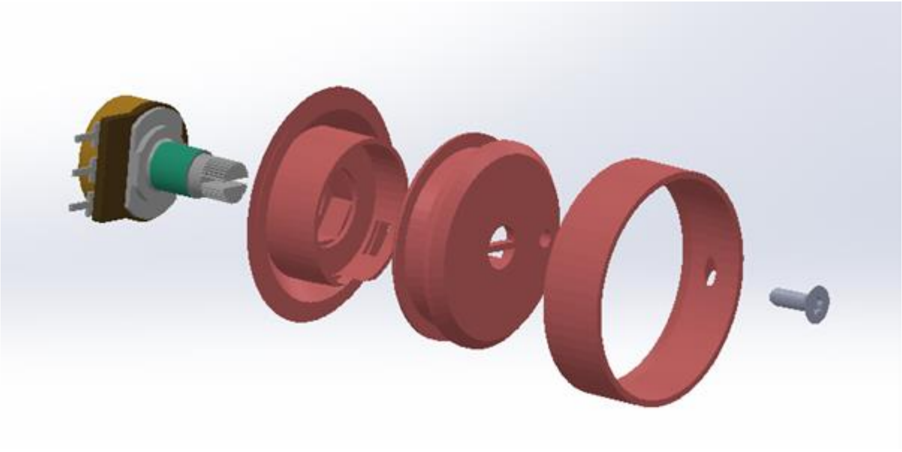
As resistance of the potentiometer, we are using is linearly related to the distance traveled by the object, you can use the following formula to calculate the curl:

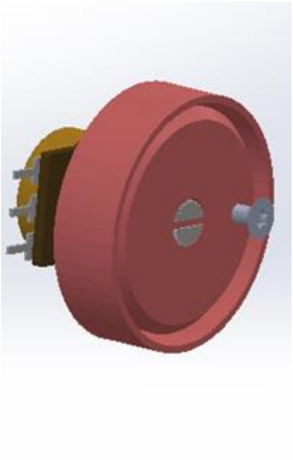
$$\boldsymbol{Curl\ =\ \left(\frac{knob\ position}{total\ resistance}\right)\ x\ total\ distance}$$

where:

- Knob’s position is the position of the knob with respect to the resistive element.
- Total resistance is the resistance of the potentiometer (10 kΩ for a B10K potentiometer), and
- Total distance is the total distance covered when fingers are closed in position of a fist, which we will measure for each user.

Again, note that the accuracy of the curl measurement will depend on the resolution and linearity of the potentiometer, as well as the precision of the measurement device used to read the voltage.

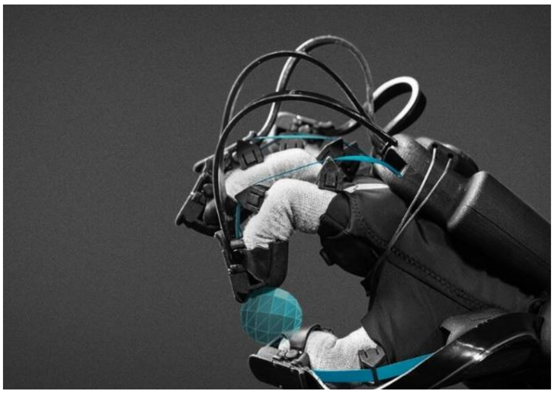


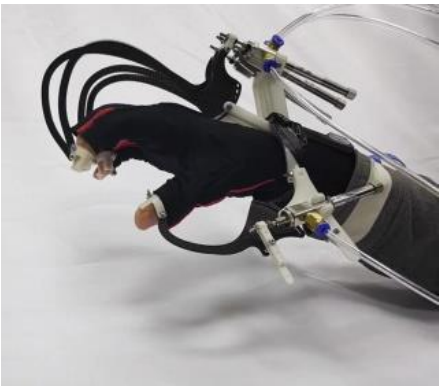


3.2 Implementing Force Feedback

3.2.1 Tendons

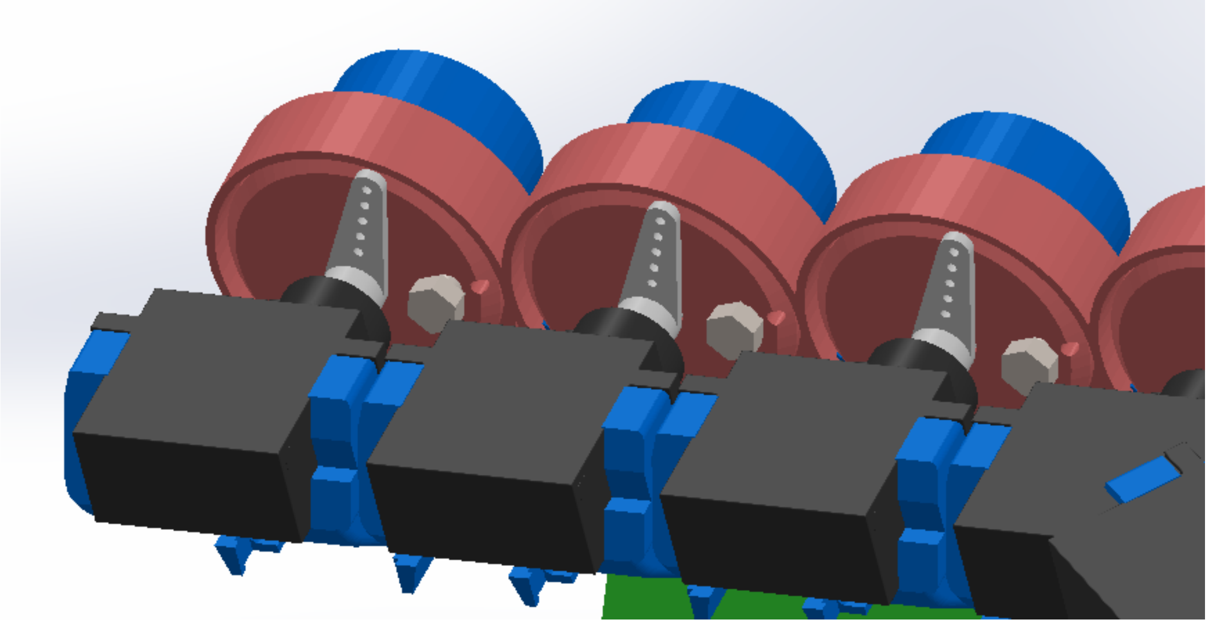
In many commercial haptic gloves, tendons are used to provide force feedback to the user. In these gloves, the tendons are attached to the fingertips and run down the length of the gloves. When the user's fingers come into contact with an object in the virtual environment, the tendons in the glove are pulled, causing resistance that simulates the feeling of touch and provides force feedback to the user.





3.2.2 Locking Mechanism

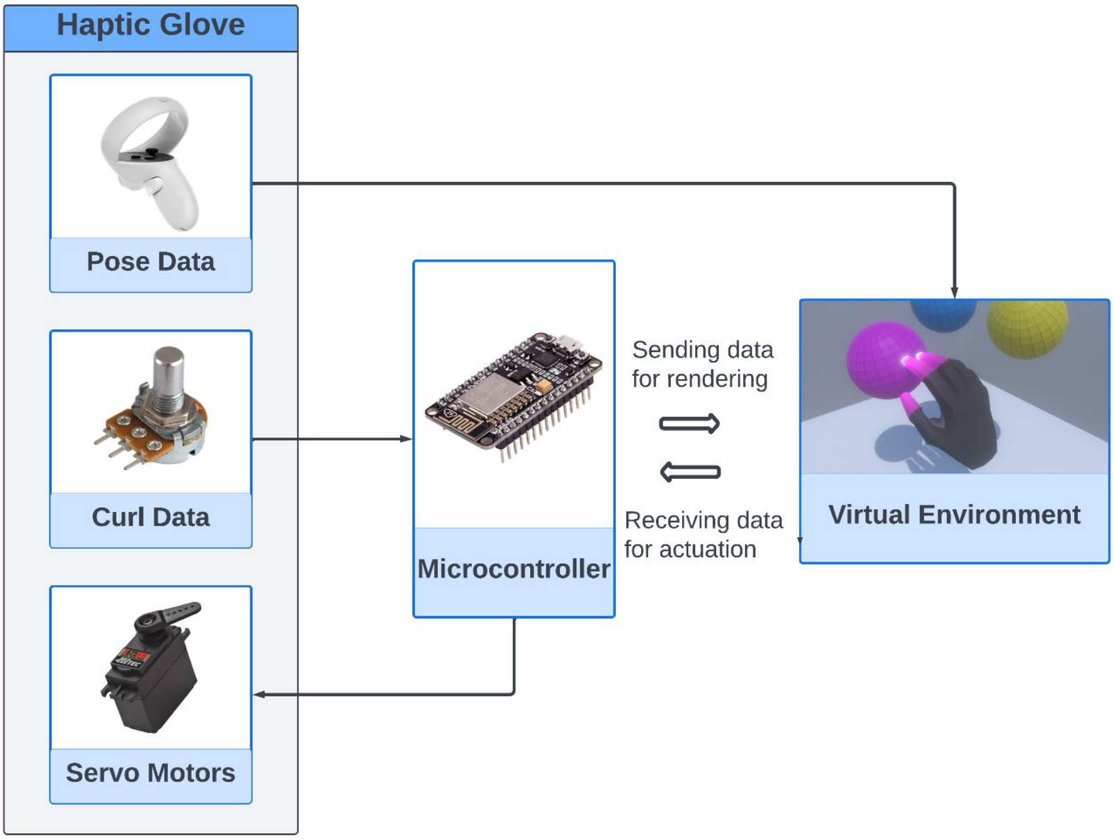
As described earlier, for force feedback, a passive or restrictive type of force would be applied to the fingers. The force will be applied using a string which will pull the fingers back by applying a force on the fingertips from the back of the hand. The spool discussed in the previous section will have a screw protruding out of it. As shown in figure:



The screwed spool cannot move past the servo arm. The arm attached to the servo will decide how much movement is allowed for the spool and hence the fingers. The servo motor, if energized, can hold a specific angle. So, when a specific input angle is given to the servo motor by the controller, it will move towards that angle and the movement of spool will be restricted from lock position till the servo's arm. This will control where to restrict the fingers.

3.3 Working

As discussed earlier, the potentiometers and the VR controller will produce the curl and pose data of the hand. This data is passed into the VR environment. If the hand approaches an interactable object in the virtual environment, a force feedback function is immediately called in the code. This function determines what should be the curl of the fingers according to the given object shape and then sends the appropriate servo angle values to the microcontroller. The microcontroller passes these values to the servo motors which move to respective angles and then hold that position. This restricts the fingers to close beyond a certain position (i.e., beyond the boundaries of the virtual object). This gives a feeling to the user that he is in fact grasping the virtual object.



3.4 Implementing Thermal Feedback

In order to get a greater sense of immersion, we intend to incorporate thermal feedback in the haptic glove. This requires a mechanism that will offer both hot and cold sensations to the user whenever he or she touches a hot or cold object in the virtual environment. After going through several techniques in the literature review, the most practical and compact solution for our application was Peltier modules.

3.4.1 Placement of Peltier Modules

The most ideal way to provide thermal feedback to the hand is by using Peltier modules on all fingers and palm. This can be done using flexible TED’s a described in the literature review. But as the flexible TED’s are not widely available, we will use common ceramic based non-flexible Peltier modules or TED’s. As these devices are not flexible, so they cannot be placed on fingers and palm as they would restrict the hand from closing. So, due to these constraints, we will only place the Peltier modules on the fingertips. As the fingertips have the highest number of sensors in the skin, it would give adequate thermal feedback to the user while allowing the user to freely open and close the hand.

3.4.2 Control of Peltier Modules

The Peltier modules need to be controlled very accurately so that they can provide the necessary hot and cold sensation at the right time. Moreover, their response should also be controlled if we want to simulate different temperatures for different objects. We can use two different configurations for controlling the Peltier modules: using relays or using PWM.

I. Relays

Relays are used in electronic circuits as switches to control the flow of current. They are particularly useful for controlling high voltage or high current devices using low voltage or low current signals. As 5 Peltier modules on five fingers will demand a high current, using a motor driver IC is not suitable. A system of two relays can be used to switch the polarity of the Peltier modules to change the direction of heat flow (for simulating both hot and cold.)

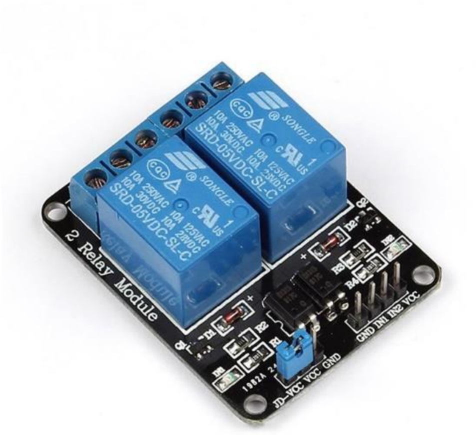
- **Advantage**: This configuration will lead to a simple design and control. At all times, the voltage and current through all the Peltier modules would be constant. Whenever, the user touches a hot object in VR, the current direction corresponding to hot flow will be switched on, and vice versa. The Peltier modules will remain off when there is not interaction or an object in VR is not hot or cold.
- **Disadvantage:** The disadvantage in this configuration is that there are only three states available: Hot, cold, and off. We cannot simulate different temperatures for different objects. All hot objects will seem to be at the same temperature. Same will be true for cold objects. This can be solved by controlling the Peltier modules using PWM.

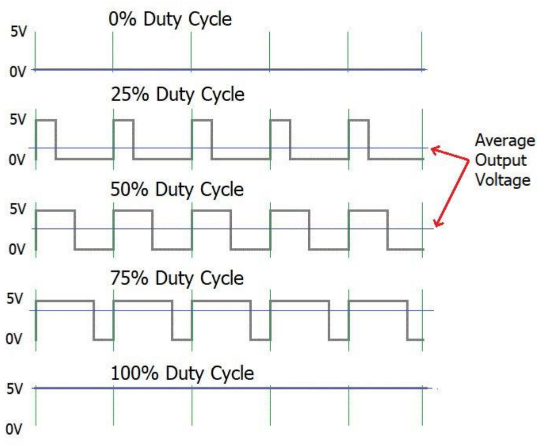
II. Pulse Width Modulation

PWM stands for Pulse Width Modulation, which is a modulation technique used to control the amount of power delivered to a load. It works by rapidly switching a digital signal on and off at a variable duty cycle, which is the ratio of the time the signal is on to the time it is off. By changing the duty cycle of the signal, the average voltage or current delivered to the load can be varied. Hence by varying the average voltage to the Peltier modules, we can change its response in both hot and cold conditions.

Advantage: By changing the average voltage given to the Peltier modules, we can simulate a complete range of temperatures from cold to hot. This would give a greater feeling of immersion in the virtual environment where different objects would have different temperatures.

Disadvantage: Using PWM with Peltier modules greatly reduce the efficiency of the device. Moreover, if the PWM frequency is not high enough, it can damage the Peltier device due to constant thermal cycles.





3.5 Unity Interaction System

The Unity Interaction System is a collection of scripts, events, and other components such as physics that provide a simplified way to create object interactions in VR. In Unity, object interaction refers to the way in which objects in a scene can interact with each other and with the player's input. This interaction can be used to create a wide range of gameplay mechanics and visual effects, such as physics-based movement, collision detection, and user interfaces. It includes features such as object grabbing, throwing, and dropping, as well as a variety of interaction events that can be used to trigger haptic feedback.

- Physics: Unity's built-in physics engine allows objects in the scene to interact with each other in a realistic way. This includes handling collisions, applying forces and torque, and simulating gravity. To enable physics in a scene, you can add a Rigid body component to objects that you want to be affected by physics. You can also set up collision detection using colliders, which define the shape and size of an object's collision detection area.
- Scripts: To implement custom object interaction behaviors, you can use scripts and events in Unity. Scripts are custom programs that you write in C# or another supported language, which can be attached to game objects to define their behavior.
- Events: Events are built-in Unity components that can be used to trigger actions based on specific conditions, such as when a collision occurs, or a button is pressed.

3.5.1 Triggering Events

When the user's hand contacts an object, the Unity Interaction System triggers the appropriate haptic feedback based on the type of interaction. The type of interaction that is to be activated in response to a variety of events or actions depends on the design of the VR application or game. Here are four common triggering events.

- Object Interaction: Tactile feedback can be triggered when the user interacts with objects in the VR environment. For example, if the user reaches out to grab a virtual object, the haptic glove or other tactile feedback device can provide a sensation of resistance or pressure as the fingers close around the object.
- Collision or Impact: Tactile feedback can also be triggered when the user collides with or impacts objects in the VR environment. For example, if the user punches a virtual wall, the haptic glove or other device can provide a sensation of impact or vibration.
- Environmental Effects: Tactile feedback can also be used to simulate environmental effects in the VR environment, such as wind or rain. For example, if the user is standing on a virtual cliff with wind blowing, the haptic glove or other device can provide a sensation of wind blowing against the user's hand.
- Gameplay Events: Tactile feedback can also be triggered in response to specific gameplay events or actions, such as firing a virtual weapon or taking damage from an enemy. For example, if the user fires a virtual gun, the haptic glove or other device can provide a sensation of recoil or vibration.

3.6 Component Selection

3.6.1 Potentiometer

The criteria for selecting a potentiometer are not excessively rigorous. In accordance with our specifications, we require a potentiometer that exhibits a considerable change in resistance, thereby becoming perceptible to a microcontroller upon turning the knob by a few millimeters.

After evaluating several potentiometers, we have found that the B10k potentiometer meets our requirements for this project. The B10k potentiometer has a resistance range of 10,000 ohms and a tolerance of +/- 20%, which is sufficient for our needs. Additionally, its sensitivity is appropriate for our application, with a noticeable change in resistance when turned by a few millimeters.

Furthermore, the B10k potentiometer is widely available and cost-effective, making it a practical choice for our project. Its compact size also makes it suitable for integration into the design of the haptic glove without taking up too much space.

Overall, we believe that the B10k potentiometer is a suitable choice for our project, meeting our requirements for sensitivity, availability, cost-effectiveness, and size.

3.6.2 Servo Motor

The basic difference between servo and stepper motors is the use of feedback. Servo motors have a position encoder attached to the drive motor that reports the actual position of the motor shaft back to the motor controller. Therefore, the servo controller may take corrective action whenever any positioning error exists. However, stepper controllers can only issue a move command, and the user has no way to be sure that the motor has actually reached the desired position.

I. Torque

The amount of force a force feedback haptic glove should provide depends on the specific use case and the desired level of realism. For our final year project, we aimed that our force feedback haptic glove should provide enough force to simulate grasping of lightweight daily objects such as mug or ball and gaming applications. For both these applications, the force feedback should be strong enough to provide an immersive experience without being uncomfortable or causing fatigue to the user's hand. The force should be sufficient to simulate the sensation of holding and interacting with virtual objects, but not so strong as to cause pain or discomfort.

Our target was to achieve the average grip force used in daily activities, which is **60 Newtons**.[1]
For reference a table of objects used in daily life with their weight and force needed to grasp them is given below.

S.no	Everyday Object	Object Mass (g)	Grasping Force (N)
1	Pen	16	0.71
2	Book	142.86	2.740
3	Wallet	169	3.518
4	Hammer	796	14.66
5	Laptop	2000	32.454

II. Weight

Wearability is a crucial factor to consider in force feedback gloves because they need to be worn by users for extended periods to provide feedback during various activities. The glove needs to be comfortable, lightweight, and not restrict the user's movement, which is especially important in applications where the user may wear the glove for several hours a day. Thus, while selecting servo motors the physical weight of the motor is also an important consideration. A design target of maximum 500g was set so that weight will not hinder normal functionality of Haptics Glove while providing necessary required torque to provide force feedback.

III. Dimensions

Wearability is a crucial factor to consider in force feedback gloves because they need to be worn by users for extended periods to provide feedback during various activities. Thus, while selecting servo motors the physical size of the motor is also an important consideration, as it can affect the amount of space that the motor takes up and the amount of weight that it adds to the system. It was made sure that dimensions of were servo motor were small enough that they will not hinder normal functionality of Haptics Glove while providing necessary required torque to provide force feedback.

IV. Operating Speed

Lag can be a significant problem in force feedback haptic gloves, especially for applications that require real-time feedback, such as gaming. Even a small delay can cause a noticeable disconnect between the user's actions and the resulting haptic feedback, which can decrease immersion and disrupt the overall experience. As such, minimizing lag and ensuring fast and accurate feedback is crucial for an effective force feedback haptic glove.

The operating speed of a servo motor can affect the lag in a force feedback haptic glove. If the servo motor operates too slowly, it may not be able to respond quickly enough to changes in the input signal, leading to lag. On the other hand, if the servo motor operates too quickly, it may introduce overshoot or instability, which can also impact the performance of the haptic glove. Therefore, it is important to select a servo motor with an appropriate operating speed and to optimize the control system for minimal lag and stable operation.

V. Operating Voltage

Servo motors can operate at different voltages, and it is important to select a motor that is compatible with our power supply.

VI. Dead-band setting

Dead band in servo motors is a term used to describe a range of input signals in which the output of the servo does not change. It is a small zone of input values where there is no motion or control of the motor. This happens due to the mechanical tolerances and hysteresis within the motor's gears and feedback mechanism. The dead band is an important consideration when designing control systems for servo motors because it can affect the precision and accuracy of the system.

VII. Pulse Width Range

The pulse width of a servo motor refers to the duration of a pulse signal sent to the motor's control wire. The control signal is typically a series of pulses that repeat at a regular interval, with each pulse having a duration that corresponds to a specific position or angle of the servo motor's output shaft. The pulse width is the time interval between the start of the pulse and the moment it ends, and it is typically measured in milliseconds. By varying the pulse width, you can control the position or angle of the servo motor's output shaft.

The larger the pulse width range results in higher resolution of servo motors.

VIII. Cost and Availability

Finally, cost is an important consideration when selecting a servo motor. Different motors come at different price points, depending on its specifications, performance, and quality. Higher-end motors with advanced features and better performance will typically be more expensive than basic models. However, the cost may not always be an indicator of quality, as there are also lower-cost motors that can perform well for certain applications. And it is important to choose a motor that offers the best balance of performance and affordability for the required application.

Availability is also one of the most recurring problems, as some servo motors may be more difficult to find or have longer lead times than others. It is important to consider the supplier and their ability to meet your needs, especially if you have specific requirements for your haptic glove.

➢ Final Selection

Upon taking consideration of all design criteria stated above, servo motor MG90S was selected. As it met all design specifications keeping glove as much as light possible, while providing required force feedback.

The table below shows the distinctive design specifications of several motors, highlighting MG90S as it met all our design criteria.

Servo Motor (SM)	Mass per SM (g)	Torque (kg)(4.8v)	Speed(sec/60deg)	Dimension (mm)	Total Mass of 5 SM	Total mass of Glove(g)
SG51R	10	0.7	0.1	25.4x12.7x22.3	50	413.5
MG90S	**13.4**	**2.2**	**0.1**	**22.5x12 x35.5**	**67**	**430.5**
S3004	37	3.2	0.23	184 x 82 x28.7	185	548.5
SG5010	39	5.5	0.2	39 x 28 x 40	195	558.5
SA-1231SG	79	32	0.14	40.3x20.2x44.9	395	758.5

Servo Motor	
Model	MG90s
Weight	13.4 g
Stall torque	1.8 kgf·cm (4.8V) 2.2 kgf·cm (6 V)
Operating speed	0.1 s/60 degree (4.8 V) 0.08 s/60 degree (6 V)
Dead-band setting	5 µs
Pulse Width Range	1000 - 2000 µs

The average grip force used in daily activities is **60 Newtons**.[1]
Servo Motor Stall Torque = T_{servo} = 0.216 Nm
Servo Motor Moment Arm = r_{servo} = 1 cm
Force Provided by single Servo Motor = F_{servo} = 21.582 N = 2.2 kg
Force Provided by All Servo Motors = 107.91 N = 11 kg
Spool Moment Arm = r_{spool} = 1.625 cm

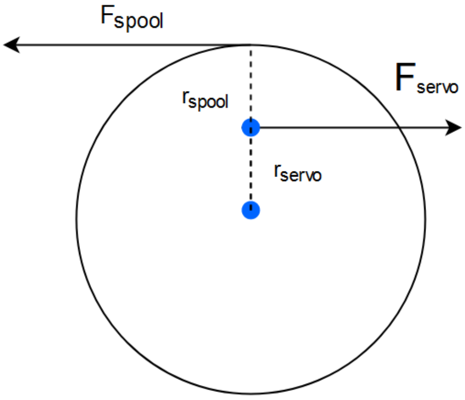
$$\boldsymbol{T_{string} = T_{servo}}$$

$$\boldsymbol{F_{String} \times r_{spool} = F_{servo} \times r_{servo}}$$

$$\boldsymbol{F_{string} = 13.28\ N}$$

Force Feedback provided to Single Finger = F_{string} = 13.28 N
Total Grip Force Provided = 66.4

The grasp force applied on average increases linearly with the weight by a factor of 0.016. [2]



3.6.3 ERM vibration motor

I. Vibration Amplitude and Frequency

As discussed in literature review of Eccentric Rotating Mass (ERM) vibration motors, there exists an interdependence between the vibration amplitude and frequency. An increase in amplitude magnitude results in a shorter period, thereby increasing the frequency. As both these parameters are interconnected, any alteration to one would inadvertently impact the other. Thus, changing the vibration frequency is often employed to modify the amplitude. Nevertheless, it is important to acknowledge that the vibration frequency holds its own significance.

II. Dimensions and Weight

The weight and dimension of an ERM vibration motor can have a significant impact on the wearability of haptic gloves and influence the selection of the motor for tactile feedback.

The weight of the motor can add to the overall weight of the haptic glove and make it feel heavy and uncomfortable to wear for extended periods. This can cause fatigue and discomfort to the user, which can reduce the effectiveness of the haptic feedback.

Similarly, the dimensions of the motor can affect the size and shape of the haptic glove. If the motor is too large, it may not fit in the desired location in the glove or may cause discomfort to the user.

In summary, the weight and dimension of the ERM vibration motor can significantly impact the wearability of haptic gloves and should be carefully considered during the selection process. A motor with lower weight, suitable dimensions, and appropriate power requirements should be selected to ensure optimal

III. Operating Speed and Power

As discussed in the conceptual design of Eccentric Rotating Mass (ERM) vibration motors to control the motor speed we simply need to adjust the driving voltage. An increased voltage means the motor can output more torque, and because the load is fixed the speed increases.

Moreover, the weight and dimension of the motor can also affect the power requirements of the haptic glove. A heavier and larger motor may require more power to operate, which can impact the battery life of the glove. Therefore, it is crucial to consider the power requirements of the motor while selecting it for haptic feedback in gloves.

IV. Noise

The noise generated by the ERM vibration motor can have a significant impact on its selection for use in haptic gloves. Excessive noise can cause discomfort to the user and distract from the intended tactile feedback. Therefore, it is important to consider the noise level of the ERM vibration motor when selecting it for use in haptic gloves.

V. Typical Lag Time

The Typical Lag Time indicates the time delay between switching on the voltage and the vibration amplitude reaching a minimum threshold (0.08 G in this case). 0.04 G is the minimum force felt by human skin. The rated voltage of the actuator is used and can be improved with overdrive. A shorter lag time is preferred for better responsiveness and faster feedback.

VI. Typical Rise Time

The Typical Rise Time indicates the time it takes for the vibration amplitude to reach 50% of its maximum value after the voltage is switched on. The rated voltage of the actuator is used and can be improved with overdrive. A shorter rise time is preferred for faster response and more precise feedback.

VII. Typical Stop Time

The Typical Stop Time indicates the time it takes for the vibration amplitude to drop below the minimum threshold after the voltage is switched off. A shorter stop time is preferred to avoid residual vibrations that can interfere with subsequent feedback. It can be improved with active braking.

VIII. Typical Active Brake Time

The Typical Active Brake Time indicates the time it takes for the vibration amplitude to drop below the minimum threshold when the reverse polarity maximum voltage is applied. For ERM motors, a shorter active brake time is preferred for faster and more precise feedback.

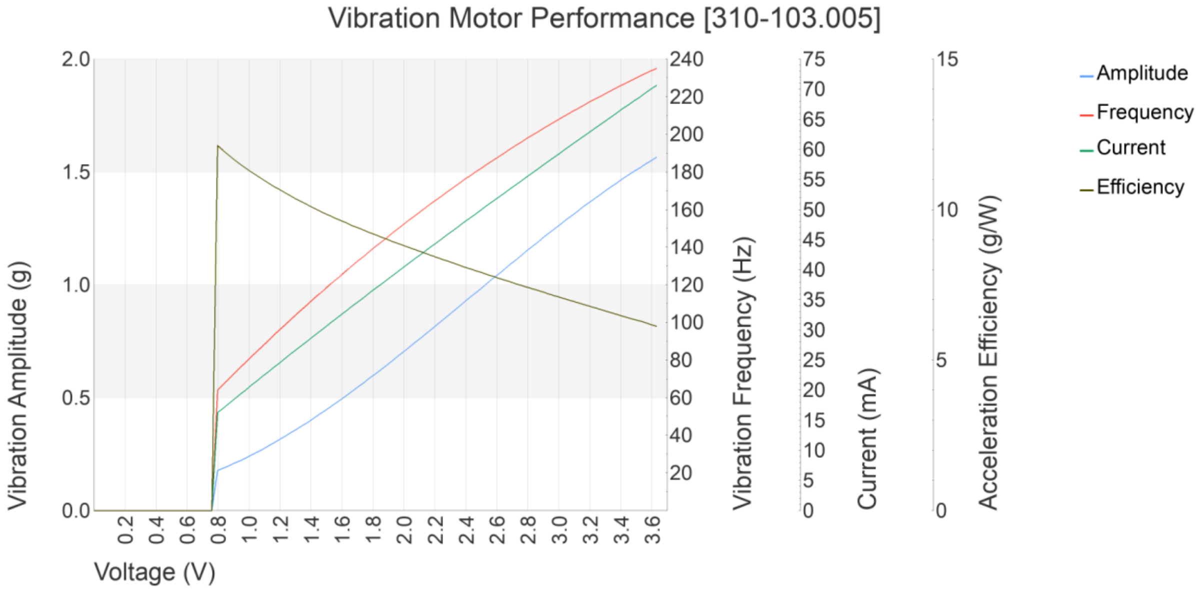
IX. Cost and Availability

Finally, cost is an important consideration when selecting ERM vibration motors. Different motors come at different price points, depending on their specifications, performance, and quality. Higher cost motors may provide better performance but may not be a practical option if the project has a limited budget. Similarly, if a specific ERM motor is not readily available, it may require additional time and resources to source, which could delay the project. And it is important to choose a motor that offers the best balance of performance and affordability for the required application.

- **Final Selection**

Upon taking consideration of all design criteria stated above, 10mm Coin Vibration Motor 3mm Type Model NFP-C1030 was selected. As it met all design specifications keeping glove as much as light possible, while providing required force feedback.

Coin Vibration Motor	
Model	NFP-C1030
Weight	13.4 g
Body Diameter	10 mm [+/- 0.1]
Body Length	2.7 mm [+/- 0.1]
Rated Operating Voltage	3 V
Rated Vibration Speed	12,200 rpm [+/- 3,000]



3.6.4 Peltier Modules

Peltier modules contain two external ceramic plates separated by semiconductor pellets. One of the plates absorbs heat (becomes cooler) and the other plate dissipates heat (becomes hotter) when a current is passed through the semiconductor pellets.

I. Heat Transfer Through Peltier Modules

It is measured in Watts, and it represents the quantity of heat that must be conveyed through a Peltier module from the colder side to the hotter side. This value can refer to either the heat produced by an object that requires cooling or the heat transferred from the object being cooled to the surrounding environment. If the heat transfer is low, the glove may not be able to adequately cool or warm the wearer's hand to the desired temperature. This can result in discomfort or reduced performance. On the other hand, if the heat transfer is too high, the Peltier module may consume excessive power, reducing the battery life of the glove and making it less practical for extended use.

II. **Temperature Difference**

The temperature difference specified in a Peltier module datasheet (ΔT) is measured on the outside surfaces of the two ceramic plates of the module. This changes with the current through the module and the temperature of the hot side. A reasonable maximum temperature difference is required so that we can simulate a wide range of temperatures from very cold to very hot.

III. **Operating Current and Voltage**

The Peltier modules have a specific current and voltage range. Generally high voltage corresponds to higher current through the module which leads to higher heat transfer through the module.

IV. **Surface Area**

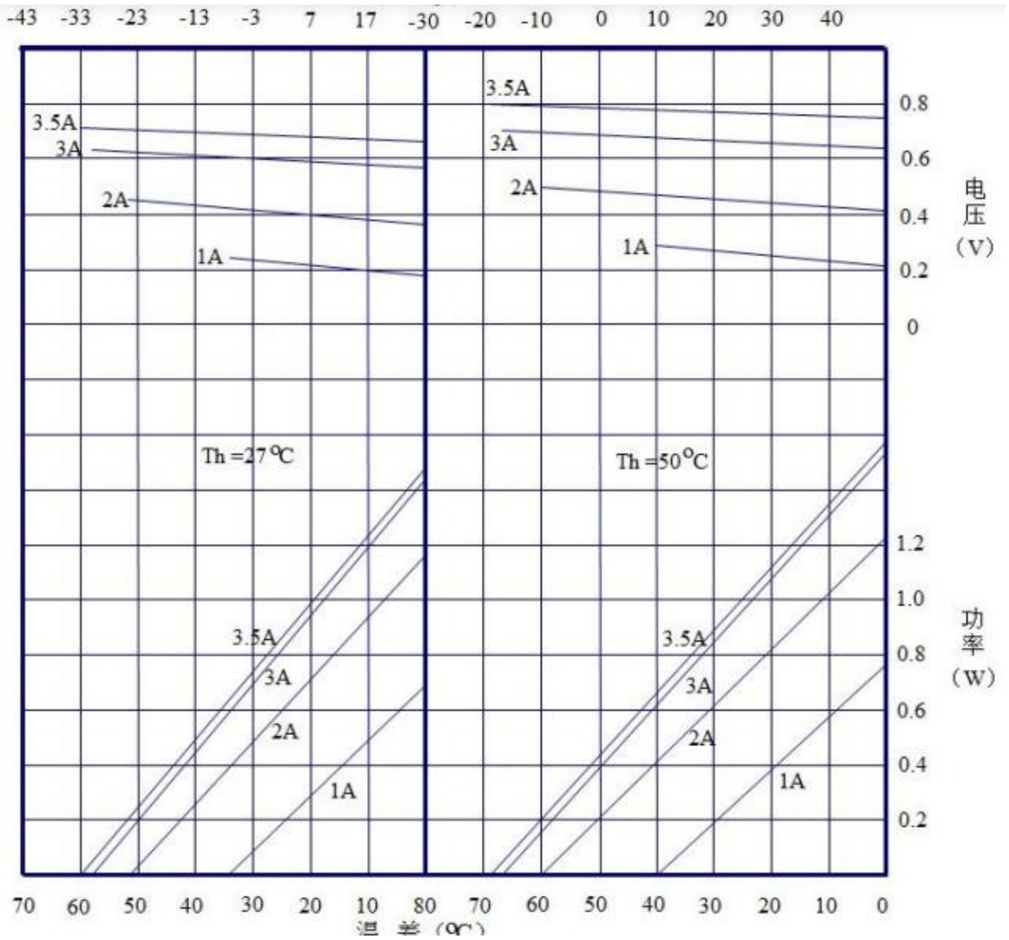
Peltier modules' surface area is generally determined by either the cooling object's area or the space allotted for heat dissipation. A disparity in size between the module's area and the available space can be corrected by incorporating a heat spreader with a low thermal impedance.

➢ Final Selection

After considering several Peltier modules, the TEC1-00703 was used. It fulfilled all the required criterion discussed above and was readily available at AliExpress. It had the following specifications and performance graphs:

Model	TEC1-00703
Max Current	3.3A
Max Voltage	0.82V
Max Temperature Difference	62 deg
Maximum Power	1.6W

Performance Graphs



3.6.5 Microcontroller

The microcontroller acts as the central processing unit that coordinates the sensors, actuators, and other components of the glove to generate haptic feedback. The microcontroller receives input from sensors in the glove, such as potentiometers that detect the wearer's hand movements and transmit that data to the microcontroller. Based on the input data, the microcontroller processes and generates appropriate haptic feedback using actuators, such as motors or vibration devices, embedded in the glove.

I. **Processing power**

The processing power of the microcontroller refers to its ability to handle the complex algorithms required for haptic feedback and sensor data processing. The more powerful the microcontroller, the faster and more efficient it can process data and generate haptic feedback.

II. Memory

The amount of memory required by the microcontroller depends on the complexity of the algorithms used and the amount of data that needs to be processed and stored. A microcontroller with sufficient memory can store and process data more efficiently, leading to improved performance.

III. Size and weight

The size and weight of the microcontroller are important considerations for a haptic feedback glove, as they can affect the overall size and weight of the glove. A smaller and lighter microcontroller is generally more desirable for a haptic feedback glove, as it can make the glove more comfortable to wear and less bulky.

IV. Communication Interfaces

Communication interfaces such as Bluetooth and Wi-Fi enable the microcontroller to communicate with other devices, such as the VR system or a mobile app, to receive commands and transmit data. Factors to consider when selecting a communication interface include the range, data transfer rate, power consumption, and compatibility with other devices.

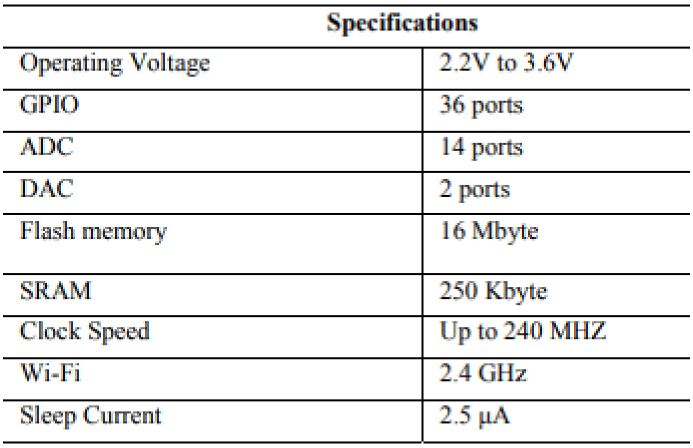
➢ Final Selection

We chose ESP32 as it fulfilled all requirements given above. It has a dual-core processor that can operate at up to 240 MHz, making it capable of handling complex algorithms required for haptic feedback and sensor data processing. It also has a large amount of RAM and flash memory, which can support the storage and processing of large amounts of data.

In addition, the ESP32 has built-in Wi-Fi and Bluetooth communication capabilities, which can enable seamless communication with other devices, such as a VR system or a mobile app. The low power consumption of the ESP32 can also help extend the battery life of the glove and minimize heat generation.

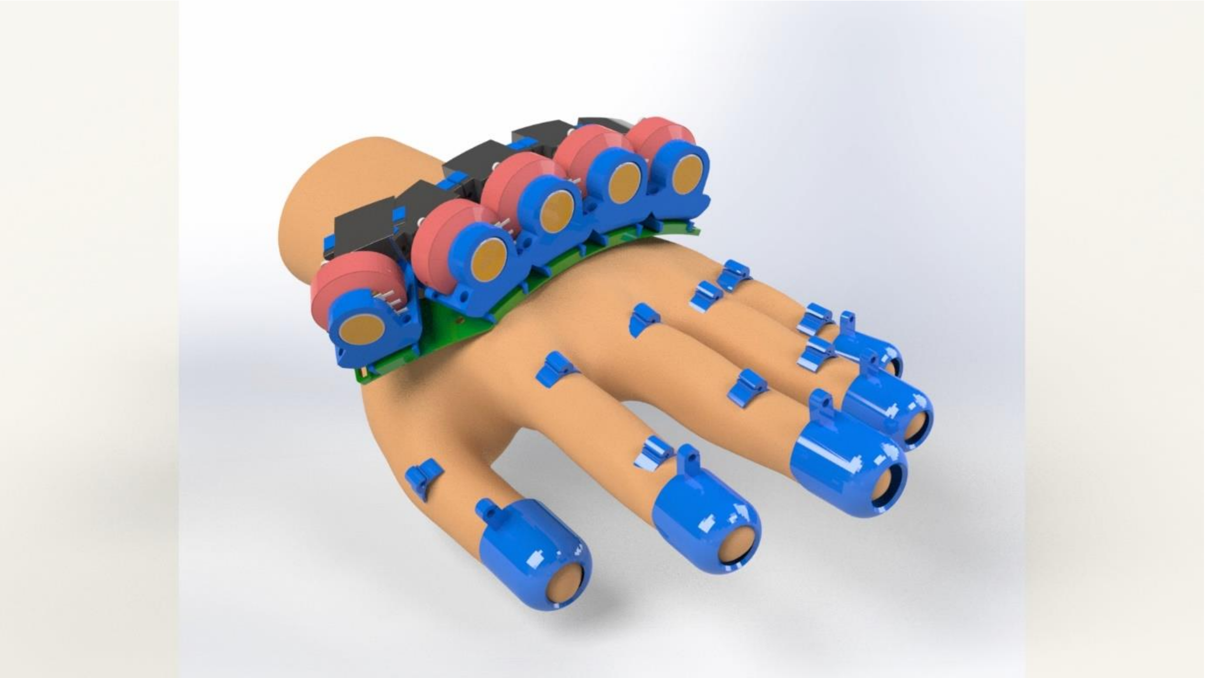
Furthermore, the ESP32 is relatively low cost and widely available, making it an accessible option for developers and manufacturers of VR haptic feedback gloves.

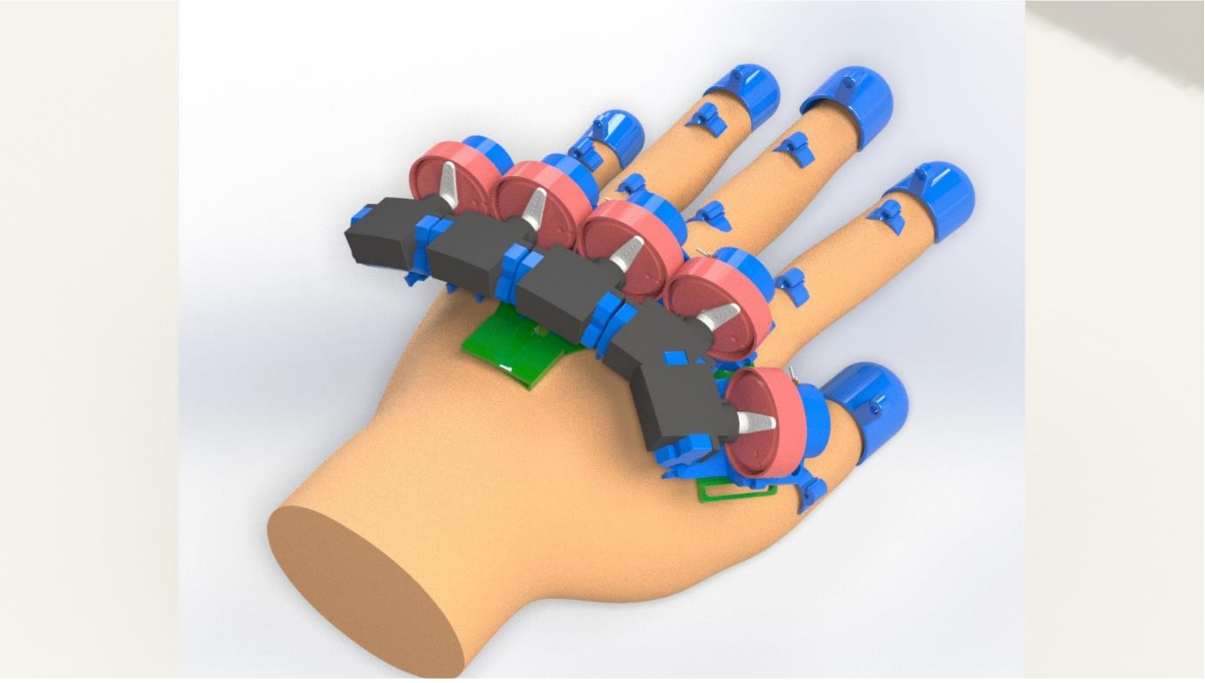
Specifications



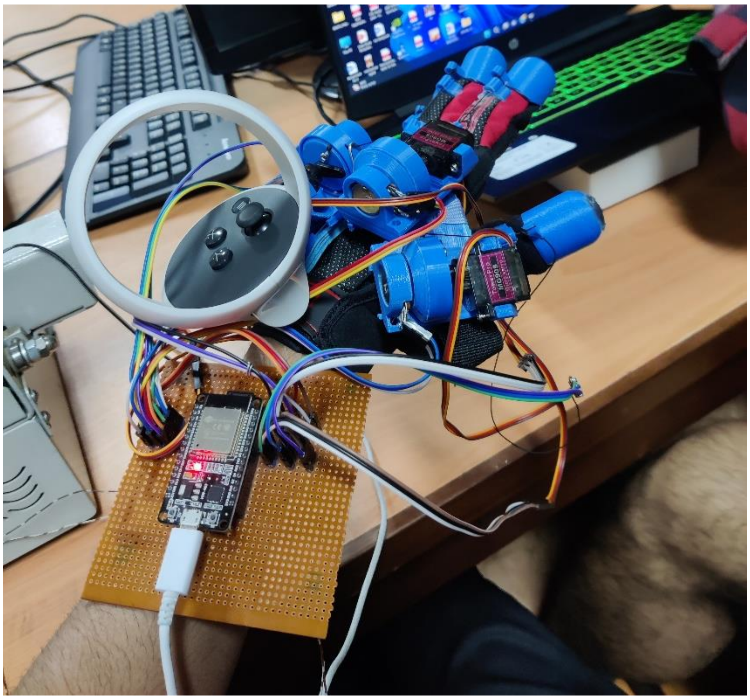
Specifications	
Operating Voltage	2.2V to 3.6V
GPIO	36 ports
ADC	14 ports
DAC	2 ports
Flash memory	16 Mbyte
SRAM	250 Kbyte
Clock Speed	Up to 240 MHZ
Wi-Fi	2.4 GHz
Sleep Current	2.5 µA

4 CAD MODELS





5 FINAL PROTOTYPE



6 RESULTS AND DISCUSSION

A virtual environment was made to specifically test 4 parameters related to the user's experience in the VR. They were:

- Immersion
- Training Effectiveness
- Comfortability
- Weight Fatigue

In order to test each parameter, the users were asked to perform a set of experiments in the virtual environment. First the users performed these experiments with the standard oculus controller and then the experiments were performed using the Haptic Gloves. After that the users were given a questionnaire in which they rated the above parameters for both the controller and haptic glove scenarios. The training effectiveness rating was given by our team based on the accuracy and completion time in the training effectiveness experiment. The details of the experiments are given below.

6.1 Experiments

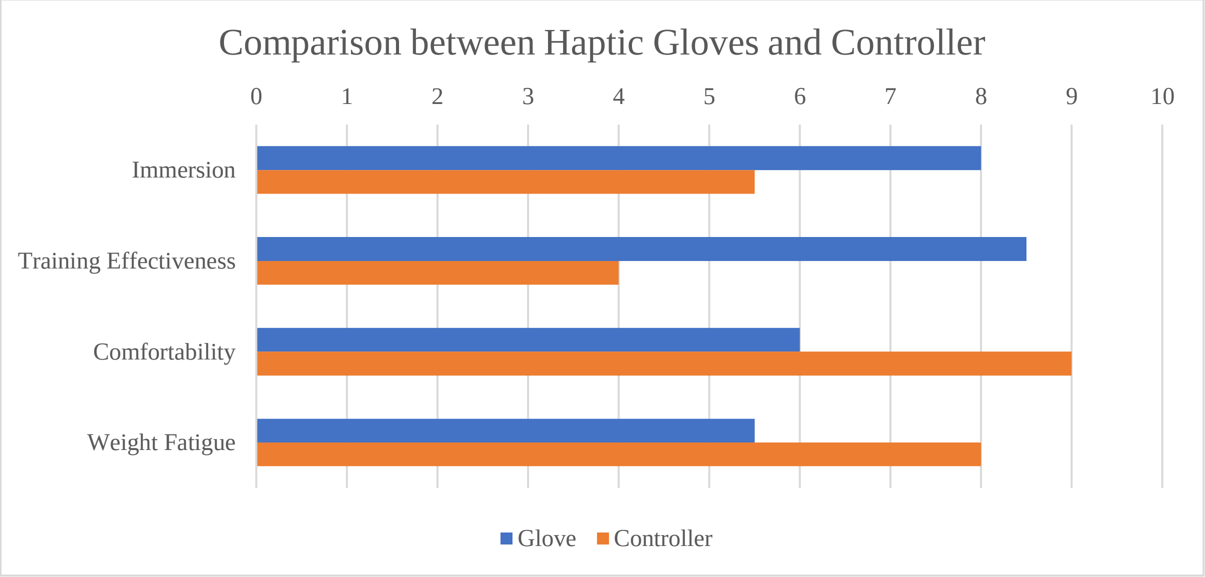
- In the first experiment, participants were tasked with using a virtual bow and arrow to hit targets at varying distances. Targets of various sizes and shapes were used. They performed the task once with the haptic gloves and once without haptic gloves with controllers. The order of using the haptic gloves and controllers was counterbalanced to minimize any potential order effects. During the experiment, visual feedback of their performance was seen on a screen.
- In the second experiment, the virtual environment included a variety of objects with different shapes and sizes. The participants were asked to pick, grab, and throw these objects at a big target within the virtual environment. Gravity and projectile physics were already included in the environment. Similar to the first experiment, participants performed the task once with the haptic gloves and once without them, i.e., with controllers.
- In the third experiment, participants were tasked with interacting with virtual blocks and arranging them into a particular shape such as a tower or a pyramid. Participants performed the task once with the haptic gloves and once without.
- In the fourth experiment we built a virtual training environment to assess virtual training effectiveness of haptics gloves as compared to traditional controller-based training. The VR environment consisted of a large part in which screws needed to be inserted at specific locations in specific order. First the users were given the instructions to complete the task. Then they were asked to replicate the steps after some time. This was also performed using both gloves and controllers on two different parts. This experiment was studied more thoroughly the team noted accuracy and completion time of the participants. Based on that a score out of ten was given to each participant.

6.2 Results

6.2.1 Collected Data

Participant Number	Immersion		Training Effectiveness		Confortability		Weight	
	Controller	Glove	Controller	Glove	Controller	Glove	Controller	Glove
1	5	8	6	7	8	6	9	4
2	7	8	3	9	10	6	7	6
3	6	10	4	9	9	5	8	6
4	5	9	6	7	9	5	10	6
5	5	7	3	9	9	5	7	4
6	7	9	4	7	8	7	8	7
7	5	7	3	7	10	5	8	5
8	6	7	6	9	9	6	9	6
9	7	9	4	8	8	7	8	5
10	4	6	3	9	10	6	7	4

6.2.2 Comparison of Median Values



6.3 Discussion

Immersion

From the data, we can conclude that most of the users gave a higher immersion rating when they were performing the experiments using Haptic Gloves. The users reported that they had a better sense of the virtual environment by using haptic gloves. By accurately capturing and simulating the movements and sensations of individual fingers, haptic gloves provide a more intuitive and natural interaction with virtual objects. Users can experience a heightened sense of presence and engagement as they can grasp, touch, and feel the virtual objects with a greater level of realism.

Training Effectiveness

From the data, we can see that people also rated higher on training effectives for the Haptic Gloves. The precise finger sensing capabilities of haptic gloves also promote fine motor skill development. Trainees can practice and refine complex gestures and movements required in specialized tasks. The gloves provide immediate and accurate feedback on the trainees' hand and finger positioning, facilitating skill acquisition and muscle memory development.

Comfortability

Although the gloves provided realistic interactions it was rated low for comfortability by the users as compared to the use of controllers. It is because the glove is still in prototype phase and functionality was preferred over comfort in this iteration. In this iteration the circuit board was bigger and was not attached to the glove. Plus, the wiring was not that much organized. However, in the following iterations, the comfortability of the glove can be greatly improved by keeping a focus on the wearability of the glove.

Weight Fatigue

The weight of the glove was given great importance in the design of the glove. However, due to the presence of servo motors for the force feedback and the attached controller, the glove still turned out to be quite heavy. This was evident from the users rating who as well felt fatigue in the hand due to the weight of the glove. This issue will also be addresses in the following iterations of the glove in which less parts and light components would be used.

7 CONCLUSION

In conclusion, our final year project successfully developed a force feedback haptic glove with a specific focus on enhancing virtual reality (VR) training experiences. The glove provided accurate finger tracking and force feedback while grabbing virtual objects in the VR environment. The glove was tested with ten participants for various parameters. The data revealed that the use of gloves improved the users' interaction with virtual objects to a great extent. This will greatly contribute to the effectiveness of VR training programs. Other feedbacks (vibrotactile and thermal) and their corresponding effects on the user experience would be tested in future versions of the glove.

8 FUTURE WORK

The research work and procurement for vibrotactile and thermal feedback was completed in this phase. In the following iterations of the haptic glove, these feedbacks would be incorporated into fingertips of the glove. The effects of these feedbacks on the user experience would be studied. Additionally, we will explore how different feedbacks can improve training outcomes in different scenarios.

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