Final Report

The Human Integrated Gripping Device

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Abstract

The Human Integrated Gripping Device is a universal device, which will allow users with limited hand strength and dexterity, the ability to perform everyday tasks. This project is specifically aimed at helping those who are living with disabilities as a result of a stroke. The finished device will facilitate the user’s ability to grasp objects and in turn perform everyday tasks. Attempts have been made to address this issue using devices such as ace bandages, splints, Velcro, tape, and prosthetics, however these have proven unsuccessful. This newly developing device will overcome problematic issues including user friendliness, weight, awkwardness, and functionality; all of which have hindered the success of its predecessors. These objectives will be accomplished by the Human Integrated Gripping Device through implementation of several technological advancements. The device will enable the user to adjust grip strength as desired with a lightweight and user friendly system. With the use of this device, the client’s way of life will be dramatically improved.

The Human Integrated Gripping Device contains several key features to ensure optimal functionality. The mechanical device is integrated with the user via a glove system, which is tightly fit to the user’s hand. This unit provides the basic abilities for gripping to occur as the mechanical ratchets tighten down within the glove, in which the user’s hand is located, and causes the user’s fingers to assume a gripping position. To release the grip, an innovative string-pawl mechanism unlatches the mechanics. Additional gripping is provided with a state of the art rubber grips and Velcro attachments. The functions of the Human Integrated Gripping Device are all precisely controlled with a user friendly controls system. All these technologies coincide to form a simple, effective, and reliable tool.
1 Introduction

1.1 Background (client and disability)

Stroke is the leading cause of debilitation in the United States. Every forty-five seconds, someone suffers a stroke, resulting in seven hundred thousand strokes per year. Of these, fifteen to thirty percent of all stroke victims, or approximately one hundred and twenty thousand people, are left with permanent disabilities. These include cases such as speech impediments, total paralysis, partial paralysis, and hemiparesis, or the weakening of one side of the body.

Stroke is not the only cause of neuromuscular disorders. Other diseases are also prevalent such as Amyotrophic Lateral Sclerosis (ALS or commonly referred to as Lou Gehrig’s Disease), where the progressive degeneration of motor neurons leads to loss of muscle control and movement. Muscular dystrophy, which includes nine separate diseases, is also fairly common, averaging approximately one person per day diagnosed in the United States. Charcot-Marie-Tooth (CMT) disease is yet another neuromuscular disease, which results in muscle weakness, degeneration and loss of sensation in the feet, lower legs, hands, and forearms.

1.2 Purpose of the project

The culmination of these conditions leads to decreased motor control and muscular abilities in thousands of people. It is estimated that fifty thousand people per year exhibit some form of these disabilities, specifically hand disabilities such as decreased motor control and muscle strength. For these patients, simple, everyday tasks that were once overlooked now become difficult and cumbersome. Imagine lacking the hand strength to hold a pencil, open a jar, or even grip a broom. It is for these reasons that the Human Integrated Gripping Device is being developed. The aforementioned patients need the benefit of a device which allows them to utilize their own hand while experiencing the advantages of assisted gripping.

1.3 Previous Work Done by Others

1.3.1 Products

Products currently on the market do not directly confront the issue that many patients are faced with. For example, there are a number of total artificial robotic hands being developed and ones that are already currently on the market. While these total robotic hands closely mimic the functions of a human hand, they are only useful in situations where patients lack a hand already. The appropriate market for these devices is for those who have undergone amputation or have lost a hand during their lifetime, or for those without a hand since birth. As can be seen in Figure 1a, total robotic hands are very complex and prove to be very expensive, while at the same time, do not benefit the clientele previously described.

Although the total robotic hand is very expensive, cheaper alternatives are on the market. The Power Glove, priced at approximately twenty dollars, is a device which claims to assist those with a weakened grip in holding a golf club. The Power Glove functions by providing the user with a strapped glove to which the golf club is attached, as can be seen in Figure 1b below. This provides additional support to the user, but still requires enough strength to conform the hand to the golf club shaft. Thus, patients who do not possess the motor control or muscle strength to contract their fingers would not
benefit from this device. The Power Glove also has limited applications, and is therefore not a solution for many people.

Additional products whose purposes are to aid in gripping include the 10-DOF Robotic Hand (Patent No. 6,505,870), seen in Figure 1c. This underactuated hand functions using pneumatic pumps and a three prong grasping approach. Although it achieves the task of gripping, it is bulky, expensive, limited in its gripping abilities, and most importantly, requires the user to grasp the device in order to use it. Thus, the purpose of assisting those who cannot grasp objects effectively in the first place, is defeated.

As can be seen, there is a large market for devices that integrate the user’s own hand while assisting in the opening and closing of fingers, with the ultimate goal of gripping objects. This device must be lightweight to accommodate weakened muscles and must also be user friendly, taking into account diminished motor control and movement. The device must slide easily on and off and in the process provide sustained comfort for the customer.

Due to the limitations of the current market of gripping devices and the needs of our customers, our team has devised a multitude of standards in the development of our
product. One of our main goals is to create a device that is light weight. The weight of the instrument is incredibly important, as the device will be worn by the user on a daily basis, hence it is vital to minimize restrictions and maximize comfort by reducing weight. The need for a highly integrated system is also present. The nature of the device is to assist gripping of an anatomical hand; therefore the apparatus must conform to the user’s hand in an efficient and fluid manner to achieve the task.

Furthermore, a user friendly interface must be provided. This will allow for simple and easy manipulations of the controls and allow the user maximum freedom. Finally, it is required that the device remain cost effective. Customers need an affordable option that offers the greatest amount of applications. This will create a device that not only satisfies the market but is also practical, useful, and lucrative. All these goals ensure a design that is simple, successful and beneficial, yet still remains cost effective.

Prior similar attempts have been made to produce a device which conforms to these requirements. In 2002, a senior design team from the University of Connecticut designed a device entitled the E-Grip. This device utilized stepper motors to extend or retract threads woven into a glove. The degree of grip strength was controlled by four voice commands, which were user specific. This project never achieved a working state and therefore the Human Integrated Gripping Device is being designed to fulfill the required needs.

1.3.2 Patent Search Results
- The 10-DOF Robotic Hand-Patent No. 6,505,870
- Power Glove
- Numerous Prosthetic Devices

1.4 Map for the rest of the report
This new design works through the combination of three basic mechanisms. The heart of the device is the mechanics. These consist of two parallel running ratchet and pawl devices that enable tightening in one direction. So as force is applied in the gripping direction, the ratchets rotate within their casing and the pawl maintains the rotation without allowing for recoil back into the relaxed position. The gripping is all controlled by the second apparatus, a release mechanism. This device consists of a string design that allows the user to allow for gripping or release grip. Finally, all of these mechanics are integrated into a glove design that enables the most user friendly and effective manipulation of the human grip.

The proceeding sections will outline three previous designs of the Human Integrated Gripping Device and provide a comprehensive explanation of each design. This leads into an analysis of the optimal design with justification for its selection as well as the final design. Also included is the project’s developmental timeline and budget, which is comprised of deadlines, milestones, and project expenses. There is also an analysis of the prototype along with a user’s manual. Finally, conclusions will be made about the overall project and its development.
2 Project Design

2.1 Design Alternatives

2.1.1 Design 1

The major concept behind the design is based on mechanics, in which a small movement with a large force at one end of a pivot point results in a larger movement at a farther distance away with a smaller force. The Human Integrated Gripping Device utilizes this model by comprising three distinct component systems: the electronic configuration system, the actuator pumping system, and the linkage system. The linkage system stabilizes finger movement, gripping, and structure, while the actuating pumps provide the necessary force to move the links. These are both dependent on the electronic configuration, which supports the power supply, sensory control and user interface. By accumulating these three components into an integrated tool, a fully functional robotic hand is formed.

The main controls for the Human Integrated Gripping device lie within the electrical configuration system. This system incorporates a series of different subcomponents such as a circuit board, dial control, pressure sensors, LED, electrical hardware, and wiring. Also, an internal battery supply provides all the necessary power to operate the device for an estimated 3 months of daily use. The premise of the electrical configuration system is to utilize this battery supply to provide a controlled amount of energy to the actuators, while maintaining feedback regulation from the pressure sensors. The dial constitutes as the user interface with the capability of allowing varied degrees of gripping force. With the varying level of degrees, the electrical signal generated is altered and in turn varies the power supply to the actuators. The pressure sensors act as a safeguard by detecting the level of pressure exerted on the user and regulating the signal to reduce grip if necessary. As the electrical signal comes out from the electrical configuration it enters into the actuator pump system.

The actuator pump system employs a set of two linear actuators whose tie rods are connected to the base of the four-finger linkage and thumb linkage systems respectively. The electrical signal causes a time step response of the linear actuators which will then cause the rods to extend outwards. As the rods extend outwards on the base of the linkage system, they force the other end of the linkage downwards. This continues until the set degree of force needed is obtained in the gripping device. Gripping is then released once the dial is set back to zero and the tie rods return to resting position within the linear actuators. One important note, the thumb’s linear actuator must begin to move at a set time interval after the four finger linkage. This will allow the fingers to enclose on the object and result in the thumb overlapping the fingers, as seen in an anatomical grip motion.

The linkage system consists of five titanium structured digits that are strapped to the anterior side of the user’s hand. Each finger consists of identical subcomponents of varying lengths. The plates proximal to the wrist make up the base, which is then connected to the mechanical tips of the digits by a parallel set of two links. The four fingers are all connected by a titanium rod that runs perpendicular to the bases. The thumb works off of a separate system than the four fingers but has an identical structure. Now, as the linear actuator’s rod pushes up, it exerts force on the lower end of the base prior to the connecting titanium rod. This upward force causes all four mechanical fingers
to go downwards on the opposite end of the titanium connector. With increasing force by the linear actuator, the linkage system causes the user’s hand to begin to curl and as a result grips the object. The links allow this to occur due to the conforming structure taking place. The force exerted by the user’s fingers on the linkage system causes the linkage to bend upwards. The springs, which run from the lower link to the upper link, limit the possibility of extension and keeps the linkage system conformed to the fingers.

The thumb linkage works off the same principle but with a separate linear actuator that only starts forcing the downward motion for gripping after the four fingers have already taken hold. The entire system will then release once the dial is turned to the off position and the rods release resulting in mobility of the mechanical fingers. This will occur in a backwards motion, as the thumb linkage removes itself first and then the four-finger linkage.

These systems comprise all the functional apparatuses of the Human Integrated Gripping Device but there are also other structural and aesthetic sections. For one, there is the introduction of a gel coated surface between the mechanical grip and the user’s hand. This lining is placed on each individual digit linkage for increased comfort. The design also consists of a rubber coated casing that surrounds all exposed sections of the Human Integrated Gripping Device. Finally, structure support beams of titanium run parallel to the actuators as well as at the bracing mounts for stabilization.

![Figure 1. Basic Drawing Showing the Major Components of the Human Integrated Hand.](image-url)
2.1.1.2 Design 1 Subunit
User Interface & Motion Control System

The user interface control box (Figure 2.) is the system by which the user operates the device. The initial state of the dial (1) is the off position. To begin the operation of the device the user turns this dial to the left. Once turned, the device is switched on and the green LED is lit indicating the device is active. The user then chooses a position (Lo, Med, Hi) which corresponds to the degree of gripping which is desired. Between each of these settings, there are additional increments which allow the user to fine adjust the grip settings between these major grip modes. Located on the side of the control box is the emergency cut-off button (3). This allows the user to turn the device completely off without using the dial if needed.

Located inside of the box is the circuit which controls the actuators and the batteries which will power the system. A control circuit is included with the actuator which will be used which eliminates the need for the construction of a circuit for this purpose. Unfortunately, a schematic of the circuit was not provided by the company.

![Diagram of User Interface Control Box](image)

**Figure 2.** Diagram of User Interface Control Box

**Actuators**

The actuators are the main components of the system. As mentioned before, two actuators will be needed: one for the operation of the forefingers and a separate one for the thumb. These two actuators will be controlled by the same knob for ease of use, however, there will be a time delay factor involved for the thumb. Due to the difference in motion of the thumb during normal gripping motion, the actuator which controls the thumb will be set at approximately a 45° angle to the forefingers’ actuator (Figure 1). The actuator which we will use in the system is a TT micro linear actuator by Copley Motion.
Systems LLC. It has a peak force of about 20lbs. with a travel speed of approximately 0.25 inches/seconds and maximum travel of approximately 15 inches. The peak force for the actuator was selected by analysis of free body diagrams of models of the fingers of the human hand during gripping. This analysis is shown in Figure 7. We assumed that the total amount of gripping force is acting at the finger tip which would be a worst case scenario. The actuator, when activated by the electronic system will respond to the setting by moving accordingly. This motion will force the back portion of the device upwards (Figure 3). As the actuator pushes up on this end of the system, a moment is created about the other end which causes it to move downwards. The force of the object being gripped acts upwards on the fingers inside of the cradles (Figure 5) which in turn act upwards on the linkage which causes each segment to bend into a gripping motion. This can be seen in Figure 4. When the user turns the dial back to the off position, the actuator rod retracts and returns the hand back to the open position.

Figure 3. Back View of Actuator with Linkage System.
\[\theta_1 = 2 \tan^{-1} \left[ \frac{2(R + D_1)}{L_1} \right] \]
\[\theta_2 = 2 \tan^{-1} \left[ \frac{2(R + D_2)}{2L_2 - L_1} \right] \]
\[\theta_3 = 2 \tan^{-1} \left[ \frac{2(R + D_3)}{2L_3 - 2L_2 + L_1} \right] \]

Figure 4. Free Body Diagram of Middle Finger with Corresponding Dimensions
Figure 5. Anterior and Posterior View of the Hand with Device Attached.
**Figure 6.** Basic Schematic of Actuator Acting on a Single Finger.

*Linkage System*

The linkage system provides contact with the actual human hand and is the actual skeletal structure of the device. The entire system will be constructed from titanium metal to provide a lightweight yet strong structure. The linkage system is broken down into three segments just like a human finger. Segment 1, which is the finger tip segment, is shaped into a cap in which the tip of the user’s finger will sit. There are two support rods on each side of the finger which runs along segment 2 and connects the finger tip cradles to the finger cradles. Connected to the proximal end of the lower support rod and the distal end of the upper support rod is a spring which facilitates the bending motion and also prevents the overextension of the segments. The finger cradles which provide support for the finger is located at segment 3. In order to determine the force needed by the actuator, the force in each segment was analyzed using statics. We assumed that the gripping force (F1) of 20 lbs. would act at the tip of the finger. From this assumption, force and moment equations were determined and the force needed by the actuator was found (Figure 7). Figure 4 shows the equations and dimensions used to determine the angles when analyzing the free body diagrams for this section. We found that to provide 20 lbs. of gripping force, 20 lbs. of force was required from the actuator. This is due to the extremely lightweight titanium design. Using a value of 0.160 lb/in\(^3\) for the density of titanium, we calculated the mass of segments 1, 2, and 3 to be 0.0216 lbs, 0.0105 lbs., and 0.0098 lbs. respectively.
Figure 7. Free Body Diagrams and Corresponding Equations of Each Finger Segment to Determine Actuator Force
2.1.2 Design 2

The major concept behind the design is based on mechanics, in which a small movement with a large force at one end of a pivot point results in a larger movement at a farther distance away with a smaller force. The Human Integrated Gripping Device utilizes this model by comprising three distinct component systems, the electronic configuration system, the stepper motor system, and the linkage system. The linkage system stabilizes finger movement, gripping, and structure, while the stepper motors provide the necessary force to move the links. These are both dependent on the electronic configuration, which supports the power supply, sensory control and user interface. By accumulating these three components into an integrated tool, a fully functional robotic hand is formed. The main controls for the Human Integrated Gripping device lie within the electrical configuration system. This system incorporates a series of different subcomponents such as a circuit board, dial control, LED, electrical hardware, and wiring. Also, an internal battery supply provides all the necessary power to operate the device for an estimated 3 months of daily use. The premise of the electrical configuration system is to utilize this battery supply to provide a controlled amount of energy to the stepper motors. The dial constitutes the user interface with the capability of allowing varied degrees of gripping force. The electrical signal generated is produced step-wise, enabling the dial to control the degree of gripping; increasing the number of steps extends the linear track, causing the linkage system to grip further and further.

As the electrical signal comes out from the electrical configuration it enters into the stepper motor system. This system employs a set of two stepper motors whose tracks are connected to the base of the four-finger linkage and thumb linkage systems respectively. The electrical signal causes a step response of the motors which acts on a gear causing the tracks to extend outwards distal of the wrist. As the tracks extend outwards on the base of the linkage system, they force the other end of the linkage downwards. This continues until the set degree of force needed is obtained in the gripping device. Gripping is then released once the dial is set back to zero and the tracks return to resting position. One important note, the thumb’s stepper motor must begin to move at a set time interval after the four finger linkage. This will allow the fingers to enclose on the object and result in the thumb overlapping the fingers, as seen in an anatomical grip motion.

The linkage system consists of five titanium structured digits that are strapped to the anterior side of the user’s hand. Each finger consists of identical subcomponents of varying lengths. The plates proximal to the wrist make up the base, which is then connected to the mechanical tips of the digits by a parallel set of two links. The four fingers are all connected by a titanium rod that runs perpendicular to the bases. The thumb works off of a separate system than the four fingers but has an identical structure. Now, as the stepper motor’s track pushes up, it exerts force on the lower end of the base prior to the connecting titanium rod. This upward force causes all four mechanical fingers to go downwards on the opposite end of the titanium connector. With increasing force by the stepper motor, the linkage system causes the user’s hand to begin to curl and as a result grips the object. The links allow this to occur due to the conforming structure taking place. The force exerted by the user’s fingers on the linkage system causes the linkage to bend upwards. The springs, which run from the lower link to the upper link, limit the possibility of extension and keep the linkage system conformed to the fingers.
The thumb linkage works off the same principle but with a separate stepper motor that only starts forcing the downward motion for gripping after the four fingers have already taken hold. The entire system will then release once the dial is turned to the off position and the tracks resume their original position, resulting in mobility of the mechanical fingers. This will occur in a backwards motion, as the thumb linkage removes itself first and then the four-finger linkage. These systems comprise all the functional apparatuses of the Human Integrated Gripping Device but there are also other structural and aesthetic sections. For one, there is the introduction of a gel coated surface between the mechanical grip and the user’s hand. This lining is placed on each individual digit linkage for increased comfort. The design also consists of a rubber coated casing that surrounds all exposed sections of the Human Integrated Gripping Device. Finally, structure support beams of titanium run parallel to the stepper motors as well as at the bracing mounts for stabilization.

*Figure 8. Basic Drawing Showing the Major Components of the Human Integrated Hand (Support System Not Shown).*
2.1.2.1 Design 2 Subunits
User Interface & Motion Control System

The user interface control box (Figure 9.) is the system by which the user operates the device. The initial state of the dial (1) is the off position. To begin the operation of the device the user turns this dial to the left. Once turned, the device is switched on and the green LED is lit indicating the device is active. The user then chooses a position (Lo, Med, Hi) which corresponds to the degree of gripping which is desired. Between each of these settings, there are additional increments which allow the user to fine adjust the grip settings. Located on the side of the control box is the emergency cut-off button (3). This allows the user to turn the device completely off without using the dial if needed.

Located inside of the box is the circuit which controls the stepper motors and the batteries which will power the system.

![Diagram of User Interface Control Box]

Figure 9. Diagram of User Interface Control Box

Figure 10 shows the basic connectivity of the major electronic components: the translator and the driver. The translator is controlled by a microprocessor into which is programmed the desired characteristics of the output such as stepping rate and stepping angle. The translator (Figure 11) consists of a circuit which converts step and direction signals into winding energizing patterns, alternating current signals for rotational movement. The driver then takes the signal from the translator and manages the current flowing into the stepper motor.
Figure 10. Electronic Configuration for Step Response
Figure 11. Translator Circuit
Stepper Motors

The stepper motors are the main components of the system. As mentioned before, two stepper motors will be needed: one for the operation of the forefingers and a separate one for the thumb. These two stepper motors will be controlled by the same knob for ease of use, however, there will be a time delay factor involved for the thumb. Due to the difference in motion of the thumb during normal gripping motion, the stepper motor which controls the thumb will be set at approximately a 45° angle to the forefingers’ stepper motor (Figure 13). The stepper motor will be connected to a gear (Figure 12-b) which will then be set on a track as seen in Figure 12-c. When the motor rotates counterclockwise, the track is projected forward, resulting in a force acting on the linkage system (Figure 13). The track runs on a rectangular aluminum box which is attached to the support surface overlying the hand. The aluminum box provides stabilization of the track as it slides across and also allows constant contact between the gear and the track (Figure 14). In addition, the box acts as a safety feature, preventing the gear from running off either end of the track by placing stops at the end of the track. Lubrication such as silicon may be needed on the interface of the track and the box to help minimize friction and provide ease of motion.

The maximum torque required was determined by first calculating the maximum force required in a worst case scenario. Using the free body diagrams in Figure 15, the force necessary from the stepper motor track controlling the forefinger linkage system is 20lbs. We assumed that the total amount of gripping force is acting at the finger tip which would be the worst case scenario. This linear force relates to a required torque of 4.57 lb-in. The equation used to estimate this torque is

\[ F = \frac{T}{R} \]

where
- \( T \) is the torque,
- \( F \) is the force, and
- \( R \) is the radius or distance from the center to the edge.

If we need 20 lbs of force then:

\[ 20 \text{ lbs} = \frac{T}{R} \text{ where } R \text{ is the radius of the gear used.} \]

In the case of the Gear in Figure 5-b: \( r = 0.2285 \text{ in} \)

\[ 20 \text{ lbs} = \frac{T}{0.2285\text{ in}} \Rightarrow T = 4.57 \text{ lb-in.} \]

Figure 12. Stepper motor system with the motor (a), gear (b) and track (c)
From this information we chose the stepper motor KML060 by Danaher Motion (Figure 12-a). The load specifications can be seen below in Table 1.

Table 1. KML060 Stepper Motor Specs

<table>
<thead>
<tr>
<th>SPECIFICATIONS</th>
<th>HOLDING TORQUE 2-ON AT RATED CURRENT (minimum) oz-in (Ncm)</th>
<th>Rotor Inertia oz-in-sec² (kg-cm²)</th>
<th>Maximum Overhang Load lbs (kg)</th>
<th>Maximum Thrust Load lbs (kg)</th>
<th>Residual Torque (typical) oz-in (Ncm)</th>
<th>Typical Motor Weight lbs (kg)</th>
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<tr>
<td>MOTOR TYPE</td>
<td>Unipolar</td>
<td>Bipolar</td>
<td>Unipolar</td>
<td>Bipolar</td>
<td>Unipolar</td>
<td>Bipolar</td>
</tr>
<tr>
<td>KML060</td>
<td>54 (38)</td>
<td>68 (48)</td>
<td>.00154 (.108)</td>
<td>15 (6.81)</td>
<td>25 (11.35)</td>
<td>2 (1.41)</td>
</tr>
</tbody>
</table>

Figure 13. Schematic of Track Motion
Figure 14. Track Support System Diagram

Figure 15. Free Body Diagram of Middle Finger with Corresponding Dimensions

\[
\begin{align*}
\theta_1 &= 2 \tan^{-1} \left[ \frac{2(R + D_1)}{L_1} \right] \\
\theta_2 &= 2 \tan^{-1} \left[ \frac{2(R + D_2)}{2L_2 - L_1} \right] \\
\theta_3 &= 2 \tan^{-1} \left[ \frac{2(R + D_3)}{2L_3 - 2L_2 + L_1} \right]
\end{align*}
\]
Figure 16. Anterior and Posterior View of the Hand with Device Attached.
Figure 17. Basic Schematic of Stepper Motor and Track Acting on a Single Finger.

**Linkage System**

The linkage system provides contact with the actual human hand and is the actual skeletal structure of the device. The entire system will be constructed from titanium metal to provide a lightweight yet strong structure. The linkage system is broken down into three segments just like a human finger. Segment 1, which is the finger tip segment, is shaped into a cap in which the tip of the user's finger will sit. There are two support rods on each side of the finger which runs along segment 2 and connects the finger tip cradles to the finger cradles. Connected to the proximal end of the lower support rod and the distal end of the upper support rod is a spring which facilitates the bending motion and also prevents the overextension of the segments. The finger cradles which provide support for the finger is located at segment 3 (Figure 17). In order to determine the force needed by the stepper motor, the force in each segment was analyzed using statics. We assumed that the gripping force (F1) of 20 lbs. would act at the tip of the finger. From this assumption, force and moment equations were determined and the force needed by the stepper motor was found (Figure 18). Figure 15 shows the equations and dimensions used to determine the angles when analyzing the free body diagrams for this section. We found that to provide 20 lbs. of gripping force, 20 lbs. of force was required from the stepper motor. This is due to the extremely lightweight titanium design. Using a value of 0.160 lb/in³ for the density of titanium, we calculated the mass of segments 1, 2, and 3 to be 0.0216 lbs, 0.0105 lbs., and 0.0098 lbs. respectively. The overall design with all the configuration systems integrated is shown in Figure 16.
Figure 18. Free Body Diagrams and Corresponding Equations of Each Finger Segment to Determine Stepper Motor Force
2.1.3 Design 3

The concept behind this design is a system which utilizes opposing stepper motors to achieve a gripping motion. This system will be implemented using a five layer glove. The first layer, which is in direct contact with the hand, is a thin inner glove lining which separates the user’s hand from any moving mechanisms and also provides comfort to the hand. The second layer is a more durable, mesh material. This is the layer in which the nylon strings will be woven. On this layer of the glove, rigid rubber caps will be placed at the tip of each finger and the thumb. A small loop at the tip of each cap provides a place to secure the ends of the nylon strings. On each finger and the thumb, nylon string is woven into the glove, starting at the distal ends and moving in until the wrist is reached. This is done on both the anterior and posterior sides of the hand. Each side of the hand works in opposition to the other.

Beginning with the anterior side, the nylon strings collect at the wrist and are bundled into one strand. These strands lead into a spindle, which is controlled by the stepper motor system. As the anterior stepper motor winds the strand in a manner which causes the palm to close, the hand is pulled into a gripping position. At the same time, the posterior motor is rotating in the opposite direction, allowing the posterior strings to extend. When the user has completed their objective, the switch controlling the motors is flipped into its opposite position and the direction of the motors is reversed. This now allows the posterior spindle to wind the strands in a manner which releases the grip while the anterior strands are allowed to extend. In order for this mechanism to work properly, the motors must run in opposite directions and the same speed at any given time. The electrical circuit system will be controlled by a three position switch. The neutral position will correspond to the device being off, while the additional two positions will control the gripping and releasing motions. The switch will require the user to hold it in the preferred grip or release state to achieve the desired position. When the switch is released it will always return to the neutral, off position to ensure safety for the user.

Above the woven string layer is an additional, lightweight, thin layer which separates the woven layer from the environment. This prevents damage to the mechanism and the user. On the anterior side of the hand, an additional pocket layer is present which houses a thin air pillow. This air pillow is included to improve contact with the item being gripped. It is controlled using a small finger pump. To discharge the air, a release valve is also present. (Figure 19)
2.1.3.1 Design 3 Subunits

Electronics

This system is based off the principle of opposing stepper motors. As the stepper motor on the anterior side of the hand winds the spindle and consequently the nylon strings, the hand is pulled into a gripping position. At the same time, the stepper motor on the posterior side of the hand must be rotating in the opposite direction, allowing the nylon strings on the posterior side to extend while the anterior side contracts. In order to control such motion between the two stepper motors, a relay circuit will be implemented. This circuit can be seen in Figure 20.
As the switch is flipped into the “a” position, the relay marked number 1 is activated and the top circuit loop is completed, providing power to both motors. Because the motors are wired in an opposite orientation, when the power supply is applied, both motors will rotate in opposite directions. When the switch is now moved into the “b” position, relay number 2 is activated, which has an opposite polarity as relay number 1. This results in both motors spinning in opposite directions relative to when the switch was in the “a” position. This provides the opposing motions necessary to create a gripping movement. The switch that controls this system is a momentary-off-momentary toggle switch. The control consists of three positions; neutral, which corresponds to “off” and up and down which control the posterior and anterior motors. As the toggle is held in the up position, the anterior stepper motor is initiated and the hand assumes a gripping position. At any point if the user releases the toggle it will automatically return to its neutral position. The down position of the toggle correlates with releasing the grip. The user must hold the toggle in the desired position for a certain time period in order to achieve the desired degree of gripping. Once released, the knob return to neutral position. This prevents the user from accidentally leaving the switch in the “on” position for too long, potentially causing injury to the user and product. These components are all located within the control box, where a 12 Volt battery supply will be located as well as the circuitry.
Stepper Motors

Two stepper motors are used in this design; one on the anterior side of the hand and one on the posterior side. As previously described, these will be controlled by a toggle switch which is adjusted by the user. Both stepper motors work by the same mechanism, the main difference being that they rotate in opposite direction while in use. Because of this, the anterior stepper motor mechanism will be described first and then simply applied to the posterior stepper motor.

When the anterior stepper motor is activated by the user, it will rotate in a counter-clockwise direction. The stepper motor is then connected to a spindle through a worm and gear drive system. Thus, as the stepper motor turns counter-clockwise, the spindle will likewise rotate. This worm and gear system can be seen in Figure 21.

![Figure 21. Diagram Displaying Stepper Motor Connected to Spindle through Worm Gear System.](image)

The gear enables a stepper motor with a lower torque to be used. If the gear has a radius of $R = 0.5''$ and a force $F$ from the strings, the worm will also have a force $F$ at the interface between the gear and the worm. But, because the radius of the worm is $r = 0.25''$, the torque is $T = F*d = F*r = F*0.25''$. Thus, half the amount of torque is needed from the motor to produce the same amount of force by using this gear system. The actual torque required can be seen in Figure 22 below. This value was calculated assuming a maximum force of 20lbs. The free body diagram and equations are seen below.
At 1: \[ T = F \times R \]
\[ T = F \times 0.5" \]

At 2: \[ T' = F \times R \]
\[ T' = F \times 0.25" \]

Therefore: \[ T' = 5 \text{ lbs-in} \]
\[ = \text{max required torque} \]

**Figure 22.** Free Body Diagram of Stepper Motor to Calculate Maximum Required Torque

This same system can be applied to the posterior stepper motor. The basic mechanism works in the exact same way, the only difference being the two motors rotate in opposite directions. This allows the grip and release motions necessary to accomplish the desired tasks. It is imperative that the two stepper motors not only rotate in opposite directions, but also at the same speeds. This ensures an even and smooth grip and release motion. Current stepper motors being looked at are 5V, bipolar stepper motors with substantial holding torque.

**String System**

The basis behind the actual gripping mechanism lies within the string system. As described in the objective, this system is a layer located between the inner and outer glove layers. The inner liner is made of polyester for comfort and protection while the outer liner is a nitrile coated flex glove with great durability. The string system liner is made from a durable mesh material. This was chosen to decrease weight and bulkiness while increasing comfort and breathability. This layer can be seen below in Figure 23.
Figure 23. View of Inside String System Layer

Nylon strings are woven within the mesh structure as seen above. At the tip of each finger is a rigid, rubber cap topped with a loop that serves as a link for the end of each nylon string. This cap provides stability and prevents tearing of the material. The same interwoven pattern is applied to both the anterior and posterior sides of this glove layer and the same mechanism is inherent to both sides. Thus, the anterior side will be discussed and then applied to the posterior side.

As the nylon strings reach the wrist, they are bundled together to form one strand. This strand is then fed into the spindle, proximal to the hand. As the stepper motor causes the spindle to wind, the strings are pulled toward the wrist, causing the fingers to contract and a gripping motion to occur. The maximum force seen at the bundle for gripping is approximately 20lbs as noted previously in Figure 22. At the same time, the posterior stepper motor is rotating in the opposite direction, allowing the strings on the posterior side to extend. If this was not the case, the strings on the posterior side would constrict the gripping motion.

When the user has achieved their desired task, the knob is held in the opposite position, which initiates rotation opposite the directions required for gripping. Thus in this case the posterior strings are contracting, while the anterior strings are extending, allowing the user to release their grip. This system provides the main mechanism for gripping and is finely tuned by the air pillow system.
Air Pillow System

Once gripping has been initiated and established by the string system, the air pillow system can be implemented to increase gripping strength. The system is located on the anterior portion of the outer glove and is held in place by a thin, durable pocket lining of nylon. The air pillow itself is based on a glove lining provided by ErgoAir (Figure 24). The lining consists of a bladder with four finger-like projections and a bulb pump with a release valve. As the user pumps the small bulb, the bladder inflates with air, resulting in increased gripping. When gripping wishes to be terminated, the user will initiate the release valve to expel the air. This is followed by the positioning of the control toggle to the release position to retract the string mechanism.

For ease of use, the bulb pump and the release valve are located on the posterior of the outer glove as shown in Figure 25. Also, the pocket lining, which contains the air pillow, includes rubber segments on its surface to increase the frictional force between it and the object being held. This will allow for better grasping of objects. These two layers are then combined with the three layer system of the inner liner, string liner, and outer glove to form the overall glove design.

Figure 24. ErgoAir Air Bladder (from http://www.ergoair-inc.com/antivibe_air_bladders.html)
Overall Design

The overall design of the device is seen below in Figure 25. This drawing takes all previously mentioned subunits and interconnects them. There are specific measures displayed in this design not previously mentioned for providing support. An open plastic forearm casing is implemented in the design as a support base for the subunits of the device. The casing is held in place by two Velcro straps which allow for adjustable fitting and a high level of support. Titanium brackets are also in place to support the stepper motors, gear assembly, and control box. These brackets come off of the plastic casting and are bolted to their respective subunits.

These subunits work in the gripping device in an integrated fashion as illustrated above. The momentary-off-momentary toggle switch controls the initiation of gripping when placed in the upward position. This causes the stepper motor on the posterior side of the hand to rotate and move the gears so that the spindle pulls the strings. At the same time, the anterior stepper motor is moving in the reverse direction and causing the strings for the anterior side of the hand to extend. The pulling force from the strings acts on the string liner and causes the glove to grip. Finer gripping strength is achieved by then inflating the air pillow through the bulb pump on the posterior of the hand. To release grip, the opposite protocol is followed. Air is released from the air pillow through the release valve. The toggle switch is then pushed to the release position resulting in the motors switching roles. The stepper motors spin in opposite directions from before which results in a release of the string force and hence a release in grip.
Figure 25. Overall view of Human Integrated Gripping Device
2.2 Optimal Design

2.2.1 Optimal Design Objective

The concept behind this design is a system which utilizes opposing stepper motors to achieve a gripping motion. This system will be implemented using a five layer glove as can be seen in Figure 26. The first layer, which is in direct contact with the hand, is a thin inner glove lining which separates the user’s hand from any moving mechanisms and also provides comfort to the hand. The second layer is a more durable, mesh material. This is the layer in which the nylon strings will be woven. On this layer of the glove, rigid rubber caps will be placed at the tip of each finger and the thumb. A small loop at the tip of each cap provides a place to secure the ends of the nylon strings. On each finger and the thumb, nylon string is woven into the glove, starting at the distal ends and moving in until the wrist is reached. This is done on both the anterior and posterior sides of the hand. Each side of the hand works in opposition to the other.

Beginning with the anterior side, the nylon strings collect at the wrist and are bundled into one strand. These strands lead into a spindle, which is controlled by the stepper motor system. As the anterior stepper motor winds the strand in a manner which causes the palm to close, the hand is pulled into a gripping position. At the same time, the posterior motor is rotating in the opposite direction, allowing the posterior strings to extend. When the user has completed their objective, the switch controlling the motors is flipped into its opposite position and the direction of the motors is reversed. This now allows the posterior spindle to wind the strands in a manner which releases the grip while the anterior strands are allowed to extend. In order for this mechanism to work properly, the motors must run in opposite directions and the same speed at any given time. The electrical circuit system will be controlled by a three position switch. The neutral position will correspond to the device being off, while the additional two positions will control the gripping and releasing motions. The switch will require the user to hold it in the preferred grip or release state to achieve the desired position. When the switch is released it will always return to the neutral, off position to ensure safety for the user.

Above the woven string layer is an additional, lightweight, thin layer which separates the woven layer from the environment. This prevents damage to the mechanism and the user. On the anterior side of the hand, an additional pocket layer is present which houses a thin air pillow. This air pillow is included to improve contact with the item being gripped. It is controlled using a small finger pump. To discharge the air, a release valve is also present. A block diagram outlining the basic mechanism of this system can be seen in Figure 27. Descriptions of each subunit introduced above will also be explained in detail below.

There are several reasons for making these design our optimal choice. These factors were based on the device specifications and other essential design considerations specific to this project. These factors include cost, safety, comfort, gripping ability, durability, weight, user friendliness and integration. With all of these factors considered, Design 3 was selected as the optimal design.

Cost is crucial when working on a limited budget. Preliminary estimates were calculated for the cost of each design. These estimates showed that Design 3 is considerably less expensive than either Design 1 or Design 2. Design 1 totaled an estimated $600, Design 2 $500, and Design 3 $330. Because Design 3 utilizes stepper
motors versus actuators and a glove system versus a titanium linkage system, the cost was drastically decreased.

Another very important factor is safety. Design 1 and 2 both implement a titanium linkage system controlled by powerful actuators that surround the posterior side of the hand. If the device failed and the actuators continued to close around the hand with excessive force, the user could face serious injury. Design 3 avoids this potential danger. By eliminating the titanium linkage system encasing the posterior hand, the risk of crushing the hand is eradicated.

The nature of this device subjects it to continual, everyday use. It is thus necessary for the device to withstand any accidents such as dropping, banging, dust, dirt, and any other factors introduced when daily activities are performed. The linkage system is susceptible to failure at each link if dropped or hit against objects. The performance would also be hindered by dirt and grime that may enter the system. Design 3’s string system eliminates the possibility of fracture at pin joints and because of this lack of joints, dirt and grime would also not be an issue.

Functionality is also of utmost importance; without an effective device, the goal of this project would not be attained. Therefore, the device’s ability to grip effectively must be taken into great consideration. As stated previously, Design 1 and 2 accomplish gripping using the linkage system. Due to this system’s slightly bulky nature, small objects may be difficult to grip. Design 3’s string system avoids this bulkiness and facilitates small object handling. An additional feature to enhance gripping ability was added in Design 3 through the air bladder technology. This system fine tunes the grip capacity and further improves device functionality.

In addition to gripping ability, integration is important to functionality. Design 1 and 2 lie above the hand and merely strap onto each finger. Alternatively, Design 3 incorporates the total hand through its glove system. This greatly increases the amount of user integration in the device and likewise increases functionality.

Ultimately, user compatibility and comfort determine the success of this device; if the user is uncomfortable, the product will not be used, regardless of its functionality. Design 1 and 2’s metal structure may pose some threat to the comfort of the user. In Design 3, a glove system is used which employs a thin inner layer that separates the user from any potentially uncomfortable, moving parts. The inner layer is made from a polyester blend that wicks away moisture and prevents the user from overheating and sweating. Design 3 is also lighter than either Design 1 and 2, further increasing user friendliness.
Figure 26. Cross Sectional View of Glove Layers.
Figure 27. Block Diagram Outlining Basic Gripping Mechanism.
2.2.2 Optimal Design Subunits

Electronics

This system is based off the principle of opposing stepper motors. As the stepper motor on the anterior side of the hand winds the spindle and consequently the nylon strings, the hand is pulled into a gripping position. At the same time, the stepper motor on the posterior side of the hand must be rotating in the opposite direction, allowing the nylon strings on the posterior side to extend while the anterior side contracts. In order to control such motion between the two stepper motors, a microprocessor and dual driver circuit is needed. (Figures 28 and 29)

![PIC16F874A Microcontroller for Step Motor Response](image)

**Figure 28.** PIC16F874A Microcontroller for Step Motor Response
Figure 29. Allegro 3967 Driver with Translator Circuit for Stepper Motors.

The microchip being used is the PIC16F874A as seen in Figure 28. This chip contains five ports (A, B, C, D, and E), two of which will be used to control driver/stepper motor response, respectively. The output signals for each of these ports will consist of disable/enable, direction, and speed. The microchip is programmed using assembly language and the outputs are in the form of binary signals (0 or 1). These three signals transfer over to the driver/translator circuit (Allegro 3697) where they control the step, direction, and enable pins (10, 11, and 15). For the direction and enable inputs, the input is either a 0 or 1. In the case of direction, a 1 designates clockwise motion and a 0 designates counter clockwise motion. For enable, an input of 0 would be ‘off’ and an input of 1 would be ‘on’. The step input however, is in the form of a square wave where the frequency of this wave is defined by the microchip and controls the speed of the motor. These responses, once translated by the driver, are signaled to the stepper motor through four leads (4, 9, 16, and 21) which then control the motor according to the input at pins 10, 11, and 15. A block diagram of microchip process and resulting stepper motor response can be seen below in Figure 30.
Figure 30. Block Diagram of Microchip Process and Stepper Motor Response
Stepper Motors

Two stepper motors are used in this design; one on the anterior side of the hand and one on the posterior side. As previously described, these will be controlled by a toggle switch which is adjusted by the user. Both stepper motors work by the same mechanism, the main difference being that they rotate in opposite direction while in use. Because of this, the anterior stepper motor mechanism will be described first and then simply applied to the posterior stepper motor.

When the anterior stepper motor is activated by the user, it will rotate in a counter-clockwise direction. The stepper motor is then connected to a spindle through a worm and gear drive system. Thus, as the stepper motor turns counter-clockwise, the spindle will likewise rotate. This worm and gear system can be seen in Figure 31.

![Diagrams of a stepper motor system showing side and top views.](image)

**Figure 31.** Diagram Displaying Stepper Motor Connected to Spindle through Worm Gear System.

The gear enables a stepper motor with a lower torque to be used. If the gear has a radius of \( R = 0.5'' \) and a force \( F \) from the strings, the worm will also have a force \( F \) at the interface between the gear and the worm. But, because the radius of the worm is \( r = 0.25'' \), the torque is \( T = F*d = F*r = F*0.25'' \). Thus, half the amount of torque is needed from the motor to produce the same amount of force by using this gear system. The actual torque required can be seen in Figure 32 below. This value was calculated assuming a maximum force of 20lbs. The free body diagram and equations are seen below.
At 1:  \[ T = F \times R \]
\[ T = F \times 0.5" \]

At 2:  \[ T' = F \times R \]
\[ T' = F \times 0.25" \]
Therefore:  \[ T' = 5 \text{ lbs-in} \]
\[ = \text{max required torque} \]

**Figure 32.** Free Body Diagram of Stepper Motor to Calculate Maximum Required Torque

This same system can be applied to the posterior stepper motor. The basic mechanism works in the exact same way, the only difference being the two motors rotate in opposite directions. This allows the grip and release motions necessary to accomplish the desired tasks. It is imperative that the two stepper motors not only rotate in opposite directions, but also at the same speeds. This ensures an even and smooth grip and release motion.

Current stepper motors being looked at are 5V, bipolar stepper motors with substantial holding torque (~5lbs.) Anaheim Automation’s 17Y series provides the necessary specification with a small, light weight design. (Figure 33) Two of these 4 lead motors will be used resulting in a combined current consumption of 560mA. They are controlled via the driver and microcontroller previously mentioned.
The basis behind the actual gripping mechanism lies within the string system. As described in the objective, this system is a layer located between the inner and outer glove layers. The inner liner is made of polyester for comfort and protection while the outer liner is a nitrile coated flex glove with great durability. The string system liner is made from a durable mesh material. This was chosen to decrease weight and bulkiness while increasing comfort and breathability. This layer can be seen below in Figure 34.

<table>
<thead>
<tr>
<th>Model #</th>
<th>NEMA Size</th>
<th>Bipolar Torque (oz-in)</th>
<th>Bipolar Current (A)</th>
<th>Bipolar Inductance (mH)</th>
<th>Rotor Inertia (oz-in-s²)</th>
<th>Shaft Diameter (in)</th>
<th># of Lead Wires</th>
<th>Weight (lbs)</th>
<th>L Length (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17Y301S-LW4</td>
<td>17</td>
<td>62</td>
<td>0.28</td>
<td>100</td>
<td>0.00096</td>
<td>1.97</td>
<td>4</td>
<td>0.8</td>
<td>1.890</td>
</tr>
</tbody>
</table>

**Figure 33.** Anaheim Automation Stepper Motor Specs

**String System**

The basis behind the actual gripping mechanism lies within the string system. As described in the objective, this system is a layer located between the inner and outer glove layers. The inner liner is made of polyester for comfort and protection while the outer liner is a nitrile coated flex glove with great durability. The string system liner is made from a durable mesh material. This was chosen to decrease weight and bulkiness while increasing comfort and breathability. This layer can be seen below in Figure 34.

**Figure 34.** View of Inside String System Layer
Nylon strings are woven within the mesh structure as seen above. At the tip of each finger is a rigid, rubber cap topped with a loop that serves as a link for the end of each nylon string. This cap provides stability and prevents tearing of the material. The same interwoven pattern is applied to both that anterior and posterior sides of this glove layer and the same mechanism is inherent to both sides. Thus, the anterior side will be discussed and then applied to the posterior side.

As the nylon strings reach the wrist, they are bundled together to form one strand. This strand is then fed into the spindle, proximal to the hand. As the stepper motor causes the spindle to wind, the strings are pulled toward the wrist, causing the fingers to contract and a gripping motion to occur. The maximum force seen at the bundle for gripping is approximately 20lbs as noted previously in Figure 32. At the same time, the posterior stepper motor is rotating in the opposite direction, allowing the strings on the posterior side to extend. If this was not the case, the strings on the posterior side would constrict the gripping motion.

When the user has achieved their desired task, the knob is held in the opposite position, which initiates rotation opposite the directions required for gripping. Thus in this case the posterior strings are contracting, while the anterior strings are extending, allowing the user to release their grip. This system provides the main mechanism for gripping and is finely tuned by the air pillow system.

**Air Pillow System**

Once gripping has been initiated and established by the string system, the air pillow system can be implemented to increase gripping strength. The system is located on the anterior portion of the outer glove and is held in place by a thin, durable pocket lining of nylon. The air pillow itself is based on a glove lining provided by ErgoAir (Figure 35). The lining consists of a bladder with four finger-like projections and a bulb pump with a release valve. As the user pumps the small bulb, the bladder inflates with air, resulting in increased gripping. When gripping wishes to be terminated, the user will initiate the release valve to expel the air. This is followed by the positioning of the control toggle to the release position to retract the string mechanism.

For ease of use, the bulb pump and the release valve are located on the posterior of the outer glove as shown in Figure 36. Also, the pocket lining, which contains the air pillow, includes rubber segments on its surface to increase the frictional force between it and the object being held. This will allow for better grasping of objects. These two layers are then combined with the three layer system of the inner liner, string liner, and outer glove to form the overall glove design.
Overall Design

The overall design of the device is seen below in Figure 36. This drawing takes all previously mentioned subunits and interconnects them. There are specific measures displayed in this design not previously mentioned for providing support. An open plastic forearm casing is implemented in the design as a support base for the subunits of the device. The casing is held in place by two Velcro straps which allow for adjustable fitting and a high level of support. Titanium brackets are also in place to support the stepper motors, gear assembly, and control box. These brackets come off of the plastic casting and are bolted to their respective subunits.

These subunits work in the gripping device in an integrated fashion as illustrated above. The momentary-off-momentary toggle switch controls the initiation of gripping when placed in the upward position. This causes the stepper motor on the posterior side of the hand to rotate and move the gears so that the spindle pulls the strings. At the same time, the anterior stepper motor is moving in the reverse direction and causing the strings for the anterior side of the hand to extend. The pulling force from the strings acts on the string liner and causes the glove to grip. Finer gripping strength is achieved by then inflating the air pillow through the bulb pump on the posterior of the hand. To release grip, the opposite protocol is followed. Air is released from the air pillow through the
release valve. The toggle switch is then pushed to the release position resulting in the motors switching roles. The stepper motors spin in opposite directions from before which results in a release of the string force and hence a release in grip.

Figure 36. Overall view of Human Integrated Gripping Device
2.2.3 Final Design

After numerous trials of different designs, the final concept that was chosen for prototyping was the ratchet and pawl mechanism design. The main concept behind the design is using a ratchet wheel that allows for motion in one direction and is restricted from moving in the opposing direction by the pawl that is lodged into the wheel. This is shown in the figure below.

![Ratchet Mechanism Basics](image)

**Figure 37.** Ratchet Mechanism Basics

The ratchet concept was extended to be used in a full mechanism that would run parallel to the hand. The mechanism consists of two units, one on each side of the hand. Each unit contains ratchet wheels at the knuckles of the hand with pawls and rigid extensions attached to each wheel. As the rigid extensions are forced down by the gripping motion, the pawl locked the position in place and maintained the grip. All these components are part of the mechanics subunit discussed below.

To control for the release of the mechanics, the release mechanism was created. Once the gripping position is no longer needed, the ratchet wheels can be allowed to retract in the opposing direction if the pawl contact can be removed. This is done by using a string system through tubular supports that led to each pawl. By pulling on the strings, one removes the pawls from the ratchet wheel and allows the hand to go back into the relaxed position. The tension on the strings comes from pulling on the string release at the glove interface pulling on the pawls to which the other ends of the strings are attached.

The final aspect of the design is the user interface. The user has complete control of the above mention mechanisms through an easy to use, tight fitting glove. An inner glove houses all the mechanics and string systems. It also contains rings that are rigidly attached to the mechanics at each segments joint of the hand for both the pinky and index finger. These rings act as the contact point for which the user exerts minimal force to achieve the gripping position. A top layer glove is also present to protect the workings of the Human Integrated Gripping Device as well as provide an aesthetic appeal to the device.
2.2.3.1 Final Design Subunits

Ratchet Mechanics

The majority of the work done by the Human Integrated Gripping Device is accomplished through the use of the ratchet and pawl mechanics. Each ratchet wheel allows motion in only one direction as the pawls prevent movement in the opposing direction. So as the user grips down on an object, the mechanics freely move into a gripping motion. The pawls are maintained in place by springs made of spring metal which allows for a tight fit to the ratchet wheel but still has forgiveness to bend backwards and free the contacts for release. (Fig. 38) All the above mention parts are laser cut from stainless steel which is then gold plated for optimal corrosion resistance. These mechanics run on each side of the left hand where interlocking pawl/ratchet combos are located at each joint. The ratchets are then extended to each other via segments of stainless steel acting as arms. These two parallel mechanisms are encased in gold plated stainless steel casings and resemble thin fingers running alongside the hand. The figures below demonstrated all the above mentioned parts. (Fig. 39)

Figure 38. Ratchet, Pawl, and Spring of one joint segment
Figure 39. Gold plated mechanics on one side of hand

Release Mechanism

Once gripping of an object is no longer desired, the pawls can be made to retract from the contact points with the ratchet wheels. This is achieved by pulling against the pawls at their respective string attachments and pushing the pawls back against the springs. As the pawl is rotated back, the ratchet wheel is no longer held in place and can easily manipulate itself back into the relaxed position with minimal effort. The strings are attached to holes at the top of each pawl. These strings are made of Kevlar, which provides superior tensile properties as well as fatigue and cut resistance. Plastic tubular casings are then implemented around each of the strings for protection and also as a means of providing a practically friction free surface for ease of pulling on the strings. (Fig. 40) All 6 strings meet at the top of the hand where they are tied into the release mechanism. This mechanism consists of an individual string release system (Fig. 41). The strings attach to each side of the glove and are in complete relaxation while gripping is occurring. Once gripping is complete, the strings are pulled by the user. As a result, the strings are forced into tension and are maintained in that state. The strings act on the pawls and retract them from the ratchets causing the hand to be free from the gripping position.

Figure 40. Tubular casing with Kevlar string
For optimal control of the mechanics and the release mechanism, a highly integrated user interface is needed. A highly durable yet flexible glove provides the best option for doing such a task. The interface actually consists of two glove layers. The first layer is a durable work glove to which the mechanics can be attached to. The ratchets are put in place in accordance to the sizing of the user’s hands (custom fit) and are then secured on by sewing 20lb. fishing line around each segment. Custom rings are then attached at each arm segment of the mechanics. These rings act as points of contact for which force from the hand can be exerted on the mechanics to allow for the gripping position to take form. The rings are made out of stainless steel 314 which has been bent then welded to appropriate fitting. Each ring is secured on to the interior glove using the fishing line as well. Finally, the tubular casings of the release mechanism are glued together on each individual side and run through the interior of the rings. These tubes are also secured to the glove with the fishing line to minimize movement.

**User Interface**
The inner glove is then protected by an outer glove which takes the form of a mitten. The mitten not only protects the inner mechanics of the Human Integrated Gripping Device but it also provides an aesthetic appeal to the device. The mitten is secured tightly to the inner glove by sewing them in conjunction so that a tight fitting interface is maintained. Next, the strings from the release mechanism are brought out to the posterior portion of the hand, where it attaches to the outer glove. The individual strings are sewed into the outer mitten for ease of use by the user. Finally, the Velcro hook is attached the thumb and the lining to the outer portion of the fingers where it can connect to form a tight fitting grip.

2.3 Prototype Design

This section will outline each component of the Human Integrated Gripping Device. Below is a block diagram outlining the makeup of the device. Each component will be explained in a logical progression, starting from the inside layer of the glove to the very outer components.

![Block Diagram of the Components of the Human Integrated Gripping Device](image)

**Figure 44.** Block Diagram of the Components of the Human Integrated Gripping Device
The following outline explains the order in which the components will be described. The headings of each subtopic explained are a component of this outline. If at any point the user gets lost, please refer to this outline to reorient oneself.

I. **Inside Glove**
   1. Index Finger Ratchet Mechanism
      a. Ratchets
      b. Pawls
      c. Rivets
      d. Springs
      e. Covers
      f. Sewed Support
   2. Pinky Finger Ratchet Mechanism
      a. Ratchets
      b. Pawls
      c. Rivets
      d. Springs
      e. Covers
      f. Sewed Support
   3. Ring Supports
      a. Rings
      b. Sewed Supports
   4. Release Mechanism
      a. Tubing
      b. String
      c. Sewed Support
      d. Tape/Glue

II. **Outer Glove**
   1. Release Strings
      a. Color Code
   2. Release Holes
   3. Release String Rings
   4. Velcro
      a. Thumb
      b. Posterior Velcro
I.1. Inside Glove, Index Finger Ratchet Mechanism

Before the inner workings of the ratchet mechanism is explained, Fig. 45 shows a picture of the completed index ratchet mechanism so the user has an idea of what is being referred to and what the final product looks like. Each component of this system is explained in more detail in the following sections.

![Completed Index Ratchet Mechanism](image1)

**Figure 45. a) Completed Index Ratchet Mechanism, b) Completed Mechanism Attached to Inner Glove**

I.1.a. Inside Glove, Index Finger Ratchet Mechanism, Ratchets.

The ratchets are the basic core of this device; without them, the device will not perform. The individual ratchets can be seen below in Fig. 46. Both the CAD drawings and the actual manufactured pieces are shown. There are two types of ratchet designs. This is necessary for the different segments of the ratchet mechanism to fit together properly. The ratchet design labeled “c” in Fig. 46 is the ratchet located at the tip of the finger, which corresponds to the ratchet labeled “3” in Fig. 47. The ratchet design labeled “d” in Fig. 46 is used for every other segment of the mechanism and corresponds to the ratchets labeled “1” and “2” in Fig. 47. The only difference between the ratchet mechanism located on the index finger and that of the pinky side is ratchet number “1” in Fig. 47. On the index finger side, the arm of this ratchet was elongated to compensate for the length of the index finger. The CAD drawing for this specific ratchet is that seen in Fig. 46a.
Figure 47 shows the inside of the ratchet mechanism (if the covers were removed from the ratchet shown in Fig. 45). The location of the individual ratchets as described for Fig. 46 is much clearer by looking at Fig. 47.
The ratchets function by allowing motion to proceed in the direction indicated in Fig. 47; the user is able to close his hand, but once closed, the hand is locked into position. This is possible because the teeth on the ratchet, combined with the pawl, restrict any movement in the opposite direction. (The pawl will be explained in the proceeding section.) With this understanding of the ratchets, we now move on to the pawls.

I.1.b. Inside Glove, Index Finger Ratchet Mechanism, Pawls.

As important as the ratchets are, this device would not work without the pawls. An individual pawl appears as shown in Fig. 48a below. Figure 48b shows the pawls in their proper locations within the mechanism.
As explained before, the user is able to close his hand freely. But, any force applied in the opposite direction is opposed by the notch of the pawl against the tooth of the ratchet. An enlarged image of the pawl/ratchet interface can be seen in Fig. 49. Please note that once the cover is in place, the spring that is overlapping the pawl in Fig. 49 would be flush with the edge of the pawl.

Figure 49. Enlarged Image of Pawl/Ratchet Interface
In order for the user to be able to release his grip position, the top of the pawls must be pulled in the direction indicated in Fig. 49. This disengages the pawl/ratchet connection and allows free motion of the ratchets once again. The release mechanism will be described in further detail shortly.

**I.1.c. Inside Glove, Index Finger Ratchet Mechanism, Rivets.**

Up until now, the ratchets and the pawls have been demonstrated as a complete unit with no regard to how these segments are joined together. This is where the rivets come into play. The rivets serve as pivot points for the ratchets and pawls and as stationary supports for the springs. There are three different size rivets; large, medium, and small. Referring to Fig. 50, the large rivets were used in location 1, the medium in location 2, and the two small rivets in location 3. The dimensions of each rivet can be seen in Table 2.

![Figure 50. 1) Large Rivet, 2) Medium Rivet, 3) Medium Rivets](image)

**Table 2. Rivet Dimensions in Inches**

<table>
<thead>
<tr>
<th>Rivet Size</th>
<th>Outer Diameter</th>
<th>Inner Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>.124</td>
<td>.06</td>
</tr>
<tr>
<td>Medium</td>
<td>.156</td>
<td>.06</td>
</tr>
<tr>
<td>Large</td>
<td>.186</td>
<td>.125</td>
</tr>
</tbody>
</table>

The mechanism which ensures that the pawl stays in contact with the ratchet is the spring. This can be seen in Fig. 50. As mentioned previously, when the covers are in place, the spring is flush with the edge of the pawl instead of overlapping as seen here. Not only does the spring maintain pawl/ratchet contact, it also allows the pawl to spring back into position after it has been pulled back for release. Individual springs before being placed into the ratchet mechanism can be seen in the figure below.

Figure 51. Individual Springs

I.1.e. Inside Glove, Index Finger Ratchet Mechanism, Covers.

Once all the components are in place and the system resembles Fig. 47, the covers are put into place. These not only provide protection for the moving parts and the user, but they also keep the pawl, spring, and ratchet in line. Once the covers are in place, the completed ratchet mechanism looks like Fig. 45a. The individual covers before being placed on the ratchet mechanism can be seen in the figure below.

Figure 52. Covers for Ratchet Mechanism

With the ratchet mechanism complete it is then attached to the inner glove. The rings are attached first, which is described shortly. To attach the actual ratchet mechanism to the glove, the ends of each system were sewed down. This can be seen in Fig. 53 below.

![Attached Ratchet Mechanism](image)

**Figure 53.** Attached Ratchet Mechanism


A picture of the completed pinky finger ratchet mechanism can be seen below in Fig. 54.

![Completed Pinky Finger Ratchet Mechanism](image)

**Figure 54.** Completed Pinky Finger Ratchet Mechanism
Every description stated in the preceding sections applies to the pinky side ratchet mechanism; only one factor distinguishes the pinky side from the index side. As is obvious, the pinky finger is much smaller than the index finger. This necessitates different size mechanism for each side of the hand. To accomplish this, the ratchet labeled “1” in Fig. 47 was elongated for the index side and shortened for the pinky side. Again, the CAD drawing for the elongated piece is seen in Fig. 46a. The ratchet on the left side of Fig. 46b is the CAD drawing for the parallel part in the pinky mechanism. Other than this one difference, both ratchet mechanisms work off the same principles and thus will not be repeated in this section.

I.3.a. Inside Glove, Ring Supports, Rings.

To attach each completed ratchet mechanism to the inside glove, ring supports were used. This consists of a series of three rings, becoming progressively smaller as the tip of the finger is approached, which surround the ratchet mechanism and the glove. These rings can be seen in Fig. 55 before they are placed on the glove. The rings for the index finger are larger than those for the pinky finger to allow room for a larger circumference finger.

Figure 55. Ring Supports Standing Alone: a) Index Side b) Pinky Side
Figure 56 displays how the rings are placed over the ratchets and the inner glove.

After being made, about 1 cm of the ring’s circumference was hammered against a flat surface. The created a more flush fit with the surface of the ratchets and thus a more secure attachment for the system as a whole.

Not only do the rings provide support for the ratchet mechanism and keep everything aligned and attached, but they also aid in the closing of the ratchets. As the user closes his hand, the portions of the rings on the anterior side of the hand give the ratchets a solid surface to push against and thus aid in the ratchets’ contraction. This dual purpose is a great benefit of the ring design.

I.3.b. Inside Glove, Ring Supports, Sewed Supports.

To attach the rings to the inner glove, small regions were sewn around the ring attaching it to the glove. Approximately five of these spots were sewn per ring; two directly around the ratchet to secure its placement and three more distributed evenly around the remaining perimeter.

The release mechanism was mentioned briefly in the preceding sections but will now be explored in more detail. Once again, in order for the user to be able to open his hand, the pawls must be pulled backwards to disengage the ratchet tooth/pawl contact point. This is where the release mechanism comes into play. This system is compromised of three tubes per ratchet mechanism (one tube per pawl) and thus six tubes all together. These tubes can be seen below in Fig. 57 before they are attached to the inner glove.

![Figure 57. Tubing used for Release Mechanism](image)


Within each tube runs one Kevlar string, again totaling three strings per ratchet mechanism and six strings all together. The end of each string is tied to a pawl. As the user pulls the other end of the string, the pawl is pulled backwards and the ratchet is released allowing a full range of motion. Each pawl must be released separately and thus each joint is straightened individually. Figure 58 shows the entire release mechanism with each corresponding part labeled.

The tubing of the release mechanism is attached to the inner glove in several ways as to prevent shifting of the tubes which could result in decreased effectiveness of the system. One such way the tubes are attached is by sewed supports similar to that of the ring supports. Multiple locations along the length of the tubing are stitched to the inner glove, encompassing all three tubes per release mechanism. This helps keep all the tubes not only bundled but also in the correct position for optimal functionality. These sewed supports can be seen labeled in Fig. 58.


In addition to the sewed supports, several spots along the tube bundles were both duct taped and gorilla glued together. This provides extra security and assurance that the tubing will remain in the correct position. These spots can be seen labeled in Fig. 58.
II.1. Outer Glove, Release Strings.

Up to this point, the inner layer of the Human Integrated Gripping Device has been explored. This layer is where all the mechanics are located and form the core of the device. Now the outer glove will be explored. It is here that the user interface portion of the release mechanism is located and this will be the focus of discussion in the proceeding sections.


The user interface of the release mechanism is composed of six strings; three strings for the index finger ratchet mechanism and three strings for the pinky finger ratchet mechanism. Because these two sides function in exactly the same way, the index finger side will be focused on. A general picture of the user interface can be seen below in Fig. 59.

![Figure 59. User Interface of Release Mechanism](image)

Each string in the release mechanism is attached to its own pawl. Because of this, the strings are color coded and the same color code applies to each side of the hand. Table 3 outlines this color code and associates each string color to a pawl number as labeled in Fig. 60 below.
Figure 60. Pawl Numbers Associated with String Colors in Table 2

<table>
<thead>
<tr>
<th>String Color</th>
<th>Corresponding Pawl from Fig. 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magenta</td>
<td>3</td>
</tr>
<tr>
<td>Blue</td>
<td>2</td>
</tr>
<tr>
<td>Green</td>
<td>1</td>
</tr>
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</table>

II.2. Outer Glove, Release Holes.

The gateways from the inner glove to the outer glove are the release holes. These are two holes located on either side of the outer glove which allow the Kevlar strings from the inner release mechanism to come through to the outer glove. One such hole can be seen in Fig. 61 below.

In order for the release strings to be secured down to the outer glove and not just dangling around, two rubber rings are attached approximately two inches away from the release holes, towards the wrist. These rings are attached by sewing sewing supports similar to those encountered many times before. The release strings are subsequently tied to these rings forming a closed loop and preventing any dangling strings that could act as a hazard to the user and the device. Figure 62 indicates these release string rings.
II.4.a. Outer Glove, Velcro, Thumb.

As the user closes his hand, the fingers are locked into position using the ratchet mechanism. In a natural grip, the thumb would then come over the top of the fingers, securing the grip and strengthening it. Because of this, added support was added to the outer glove to accommodate the thumb. To the thumb was added the hook portion of Velcro. This can be seen below in Fig 63.

Figure 63. Velcro on Thumb

II.4.b. Outer Glove, Velcro, Posterior Velcro.

The corresponding Velcro to the thumb is located on the posterior side of the fingers. A large area is covered giving the thumb a large contact region. This is helpful when the user grabs various size objects as the placement of the thumb will be varied with respect to the object size and shape. This Velcro can be seen below in Fig 64.
Figure 64. Velcro on Posterior Side of Fingers
Instructions

Step 1. Place left hand inside of the Human Integrated Gripping Device with the assistance of the right hand or someone else. Ensure that the glove is tightly on and fingers are in appropriate sections.

Figure 65. Putting on Glove
Step 2. Place the glove around the object that one wishes to grasp.

Figure 66. Grasping File
Step 3. Close the Human Integrated Gripping Device onto the object of interest. The may be done using the left hand to the best of one’s ability. The ratchets can be more firmly gripped by clasping down on both sides of the mitten.

Figure 67. Tightening Ratchets

Figure 67. Gripping Position
Step 4. Hook the thumb of the Human Integrated Gripping Device to the top of the Velcro layered finger section of the mitten. Grasp the hook on as tightly as possible for firmest grip desired.

Figure 68. Attaching Thumb to Glove

Figure 69. Ready for Use
Step 5. Use the grasped object as desired until gripping is no longer desired.

Figure 70. Glove in Action
Step 6. To stop gripping, start by removing the hook from the thumb off the mitten. Remove the object being gripped with opposing hand or placing it down on firm surface.

Figure 71. Removing Thumb

Figure 72. Removing Object
Step 7. Pull on the release strings on the right side of the hand first. Pull the strings in the following order: red, blue, green. The mechanics will naturally open up one at a time with minimal force outwards while pulling on the string. (Note: if mechanics do not release properly, please check Troubleshooting for appropriate actions)

![Figure 73. Releasing Right Side of Glove](image1)

![Figure 74. Releasing Right Side of Glove Showing Extension](image2)
Step 8. Next, pull on the release strings on the left side of the hand. Pull the strings in the following order: red, blue, green. The mechanics will naturally open up one at a time with minimal force outwards while pulling on the string. (Note: if mechanics do not release properly, please check Troubleshooting for appropriate actions)

Figure 75. Releasing Left Side of Glove

Figure 76. Releasing Left Side of Glove Showing Extension
Step 9. Once the mechanics are in a straight line running parallel with the user’s fingers, remove the glove from the left hand and store the Human Integrated Gripping Device for later use.

Figure 77. Glove in Straight Position

Figure 78. Removing Glove
Testing

The Human Integrated Gripping Device has undergone several stages of testing to ensure its proper functionality. Initial stages of testing were concerned with mechanical stability. Latter stages began concerning more with prototype success and performance to the desired specifications. Final stages of testing were with actual users and mock trials.

Research shows that the maximum grip strength is approximately 25lbs. Therefore it is necessary from the ratchet mechanism to withstand at least 25lbs. Testing was done on this system using an Instron Tension Testing Machine. The setup can be seen in the figure below.

Figure 79. Tension Testing

When this testing was performed, it was determined that the ratchet/pawl interface withstands 60 lb-ft, giving the device a safety factor of almost three, more than enough for the device to function well.

Before the final prototype was completely assembled, testing was done on the ratchet mechanism, ring supports and release mechanism. After testing the ratchets, the optimal position on the inner glove was determined and they were sewn into place. Similar testing was performed on the ring supports before attaching them permanently.
As the release mechanism was being constructed, it was tested at every point along the way to ensure proper functioning. This testing can be seen in the figure below.

![Testing Ratchet Mechanism](image1)

**Figure 80.** Testing Ratchet Mechanism

Final testing involved using the completed prototype to grasp various objects. This not only tested the ability of the ratchets to maintain the gripping position, but it also tested the ability of the release mechanism to properly release the ratchets. Pictures of this testing can be seen in the figures below.

![Prototype Testing](image2)

**Figure 81.** Prototype Testing
3 Realistic Constraints

Throughout the entire design, specific standards and protocols were always followed. These include considerations in engineering standards, economics, environmental factors, sustainability, manufacturability, ethics, safety, social and political issues. When developing any project it is important to take these factors into consideration as they can have gross effects on the individuals associated with the project. Therefore, it is critical to adhere to the highest standards.

Engineering standards qualify as the protocols and procedures followed in the engineering of any device. These consist of items such as dimensional analysis, material analysis, mechanical analysis, and testing. For our design, we went through rigorous calculations including free body diagram analyses of the forces involved in gripping and on the ratchets themselves. Calculations were also done on ratchet dimensions and the correlated strengths. Several materials were looked into as to ensure the mechanical integrity of the device. Considerations also included that of corrosion, specifically bimetallic corrosion, wear, fatigue, strength, toughness, and durability. We used all these concerns in our prototype development, which once complete endured numerous tests. Testing was both done for mechanical strength and user friendliness/effectiveness.

Along with engineering standards, economic concerns were always prevalent throughout its development. One must always account for the cost to benefit ratio when designing a device if the device is to be successful on the market. We began this by choosing materials and processes that were cost effective. Meaning, they provided the necessary functionality to meet or exceed specifications, but at a minimal cost. Also, in keeping with economic standards, a detailed budget was maintained. This enabled us to constantly visualize our expenses and minimize cost whenever possible. By following all these procedures, we were able to produce a product that is not only high functional and effective but at a low cost for an ever demanding market.

When dealing in the industrial business of design development and production, it is vital to create an item which is not only functional but also durable. To do this, our group followed strict guidelines in ensuring the sustainability of the device we created. This began with the use of stainless steel throughout the mechanics of the device. Gold plating was also used on these parts so that corrosion would be minimized and lifetime extended. The introduction of an outer glove also served as a protective environment for the workings of the Human Integrated gripping Device. Finally, severe testing of the device with numerous trials proved the functionality and durability of the device.

Due to the size limitation and intricacies of the parts, our design involved a high level of specialized manufacturing. Most of our efforts in this went towards the development of the mechanics. We followed all protocols for engineering these parts by going through a well known professional engineering firm. The only concern with manufacturability is that it is hard to duplicate these parts due to their specialized nature. Also, it is not a simple procedure to combine all the mechanics used, therefore making it a difficult task to mass produce such an item.
All ethical concerns were taken into consideration from the start of the project. Research was done to determine if any other companies or research groups attempted and/or succeeded at completing a project similar in nature. No such projects were found, even after a thorough patent search. Thus, it was safe to proceed with our ideas and know that the design would not be impinging on other groups’ work.

Many different designs were created before ultimately reaching the optimal design. Health and safety was a major concern when choosing which design would be the final product. Many of the previous designs incorporated actuators and motors which provided significant forces. If these devices malfunctioned, serious health and safety issues could occur such as the possibility of crushing the hand. Because severe consequences such as this existed, a simple device with fewer risks was desired. The current prototype fulfills these needs and provides a safe and effective way to meet the desired specifications.

Social and political constraints were never a huge factor in the design of the Human Integrated Gripping Device. Because we adhered to ethical guidelines when researching and developing this product, no problems would or can occur with regards to this issue. The function this device serves to fulfill does not prove to be a social or political issue of great debate. In fact, by creating this product, many people in society may be helped, as a huge number of people each year are affected by stroke and other muscle affected issues.

Designing and manufacturing a device for ultimate sale to the mass public has many more implications than just making a product that works. Strict engineering standards must be adhered to while at the same time, economics, sustainability, manufacturability, ethics, and social and political concerns must also be taken into consideration. It is only when these factors are balanced that a successful device is created. The Human Integrated Gripping Device has taken all of these considerations into account and has created a device which meets its specifications, while at the same time excels in cost effectiveness, sustainability, and ethical standards.
4 Safety Issues

The final project managed to handle most applicable safety issues very well. The device was designed so that the user is able to easily fit the glove onto his/her hand and easily remove the glove from his/her hand. Being that we have managed to exclude any electronic components in the project completely avoids the issue of components shorting out and causing fire hazards which could pose a very serious threat to the user of the device.

Mechanically, since the device is controlled entirely by the user, in that the user manually by using his/her own strength, determine how tight the gripping position, the issue of the device automatically moving the grip in too tight is avoided. If there happens to be a case in which the release strings get stuck, the outer glove is easily removable so that the user can access the pawls and release the ratchet to free the grip.

No harsh chemicals were used in the construction of the device therefore there is a very little chance of irritation, or allergic reaction to the device. The only skin to device contact is the user’s hand with the common cotton/polyester work glove. If the instructions are followed and the device is used properly, there should be no contact with any other component of the device and the user except for the outer interface of the device. As a result of this design feature, almost all biocompatibility concerns are dismissible unless the user has an allergic reaction to cotton or polyester.

However, due to the fact that most of the inner components of the device are made of metal, there is an eminent hazard if the user were to carelessly use the device around exposed wires or other electrically charged devices where the glove is exposed to the danger. This is why we strongly urge the user to avoid using the device around electrical components.

Another issue that may arise, although not purely a safety issue but may have more to do on the side of the comfort of the device for the user is the issue of ventilation of the user’s hand once operating inside the device. Because of the double layered glove design, the device may be poorly ventilated which could cause the user’s hand to sweat and become slightly uncomfortable depending on the user. This should not become a major problem however, since the device will not be attached to the user’s hand all day long.

In formulating and executing this design, most of the safety and comfort constraints were planned for and although some have been avoided more than others, overall the device poses very little safety threats to the user.
5 Impact of Engineering Solutions

Based on the optimal design of our device, there are many positive impacts of our applied engineering solutions that are applicable in a societal, environmental, and global context.

Being that stroke is the leading cause of debilitation in the United States and every forty-five seconds, someone suffers a stroke, resulting in seven hundred thousand strokes per year and that muscular dystrophy (a common result of strokes), which includes nine separate diseases, is also fairly common, averaging approximately one person per day diagnosed in the United States. It is quite evident that our device has a huge societal impact; at least as far persons with muscular dystrophy disabilities are concerned. Also, of these, fifteen to thirty percent of all stroke victims, or approximately one hundred and twenty thousand people, are left with permanent disabilities. These include cases such as speech impediments, total paralysis, partial paralysis, and hemiparesis, or the weakening of one side of the body.

The culmination of these conditions leads to decreased motor control and muscular abilities in thousands of people. It is estimated that fifty thousand people per year exhibit some form of these disabilities, specifically hand disabilities such as decreased motor control and muscle strength. For these patients, simple, everyday tasks that were once overlooked now become difficult and cumbersome. Imagine lacking the hand strength to hold a pencil, open a jar, or even grip a broom. It is for these reasons that the Human Integrated Gripping Device was developed. The aforementioned persons need the benefit of a device which allows them to utilize their own hand while experiencing the advantages of assisted gripping.

Our device, being that it allows those persons who currently have a muscular dystrophy disability to use their own limbs and their remaining strength to accomplish daily tasks involving gripping, is surely a positive impact on the society. We also ensured that no patents or right to previously similarly developed devices were infringed.

Environmentally, the final design of the device is very adherent to the conservation of all things considered environmentally precious in today’s world. Materials used for the final design of the device are not acquired in any way harmful to the environment. Our design materials include Kevlar string, plastic tubing, stainless steel metal, and everyday work-gloves. The procurement and use of these materials in no way violated any environmental laws that are known to us. Also, during the operation of the device, no harmful particles, chemicals, or harmful biological material is emitted. Also, there is no foreseen eminent threat to the environment through the disposal or any malfunction of the device.

Globally, the final device also has a positive impact on the global society. Being that all over the world people experience strokes and as a result are left with, many times, some form of muscular dystrophy, this device can be used globally. However, when design, global constraints were not taken into consideration, such as medical devices
regulation laws in other countries of the world outside of the US. In this area, there may be a problem if global use is intended and in that case, it would be necessary to go back and review some popular regulation laws of others countries of the world outside of the US on devices such as the Human Integrated Gripping Device.

As far as the global environment is concerned, the impacts are pretty much the same as the regional environmental impacts. Again, materials used for the final design of the device are not acquired in any way harmful to the environment. Our design materials include Kevlar string, plastic tubing, stainless steel metal, and everyday work-gloves. The procurement and use of these materials in no way violated any environmental laws that are known to us. Also, during the operation of the device, no harmful particles, chemicals, or harmful biological material is emitted. Also, there is no foreseen eminent threat to the environment through the disposal or any malfunction of the device. However, there may be laws that are set in place globally that we may have overlooked but it is hard to believe that the assembly of our device from such common materials would become a problem. Even so, if the need were to arise we would, bound by our code of ethics, be obligated to go back and examine any global laws that may hinder the use of our product globally.

Since our product search resulted no real solution to the problem that we were seeking to solve, we did the best with the knowledge we had acquire from our research of current products, patents etc. and design a simple, lightweight, inexpensive, and user-friendly device that works. Previous were either incompletely, costly, too bulky, impractical, or too complex to satisfy the need of the group whose use this type of device is intended for.

Our engineering solution provided very minimal, if any, negative impacts on the global, economic, environmental, and societal arenas. As far as societal impact is concerned, we have designed a device that meets the needs of a very real population of our society.

Environmentally, we were able to avoid using any materials or processes in our development of our device that would lead to negative impacts on our environment and any environmental laws in place in the US.

We have also been able to develop a device that will be of no negative consequence globally (environmentally, or to the people) as far as our knowledge extends at this point on global issues concerning devices such as ours.
6 Life-Long Learning

Lifelong learning is the continuous acquisition of knowledge occurring at all levels including formal education to earn a college degree to informal education for one’s personal benefit. Lifelong learning transpires at every stage of one’s life in order to provide an ever growing base of knowledge which can benefit each aspect of one’s life from success in the working world to personal self-actualization, allowing one to pursue continuous personal development. Doing so enables one to keep up with the pace of the ever changing world. New developments are continuously being made and new technologies emerging. In order to stay competitive in the working world, one must always be looking to improve his or her abilities and skills. It is estimated that three years after the receipt of a college degree, one’s education is out-dated. Therefore it is imperative to stay current in order to succeed. There are many ways to practice this perpetual pursuit of knowledge. These include continuing formal education to receive numerous degrees, joining professional organizations, attending conferences and taking non-credit courses.

With this in mind, working on the Human Integrated Gripping Device has contributed to the pursuit of life-long learning. Because of the way the course is outlined, senior design has provided an introduction to the industry of product design and development. The experience of learning from failure was an important one in this design process. This was accomplished by determining many different design options before reaching the optimal design seen here.

New technical skills were also acquired while working on the Human Integrated Gripping Device. The process of laser cutting was a new technique introduced to the team that was instrumental in creating the ratchet mechanism. Phil also learned to sew, an important task in life. Using the machine shop was very important during the production of the prototype. Lathing, milling, and welding were just some of the many skills introduced by working on this project.

Besides the technical skills learned, many work skills that can be used in the industry were obtained. These include such business skills as budgeting, following and maintaining a timeline in Microsoft Project, and giving weekly updates. Also important in the engineering field is maintaining an engineering notebook, following a structured work schedule, writing reports, giving presentations, and working as a team.

Through working on the Human Integrated Gripping Device, a new perspective on research and design processes as a whole have been gained. The many design changes required the team to perform extensive research in not only well known engineering fundamentals, but also in new and upcoming ideas. It has helped in knowing where to find sources when needed, and what sources are reliable or not.

Overall, the senior design experience has culminated our four years of education at the University of Connecticut and has helped us apply it practically. This brought about a variety of new technical skills including lathing and milling and also new
business skills that we can carry into our future. This project has set the foundation for life-long learning that we shall build upon in the years to come.
## Team 5 Expense Report

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<td>5.27</td>
<td>5.27</td>
</tr>
<tr>
<td>24 pin SOIC to 24 pin DIP adapter</td>
<td>Jameco</td>
<td>1</td>
<td>10.94</td>
<td>10.94</td>
</tr>
<tr>
<td>High Density Polyethylene sheets</td>
<td>US Plastic</td>
<td>1</td>
<td>33.32</td>
<td>33.32</td>
</tr>
</tbody>
</table>

**TOTAL** 179.30

**Allotted Budget** 750.00

**Expendable Budget** 570.70
TEAM MEMBERS CONTRIBUTION TO THE PROJECT

TEAM MEMBER 1

Team member 1 is Emily Pribanic. Her contribution to the project involved the ratchet mechanism. From the conception of the idea of using a ratchet mechanism, she created the CAD drawings used to program the laser machine to cut the parts. This involved many revisions and design changes. As a part of this same mechanism, she designed the rivets, springs, and covers which were an integral part of the entire design.

TEAM MEMBER 2

Phil Batista is team member 2 and his main tasks were developing the glove interface for the Human Integrated Gripping Device and design development. Phil came up with the initial ratchet and pawl design that was further developed by the group into the mechanics used in the prototype. With that in hand, Phil continued his efforts on many designs for the user interface. His work was mostly involved in building the inner glove with the association of the ring and release mechanism attachment. He then contributed the outer glove design with the release mechanism attachment and release. Finally, Phil performed many of the prototype tests due to the similarities between his hand dimensions and that of the client.

TEAM MEMBER 3

The final member of the group is Lyndon Charles. His job description consisted of developing and creating the release mechanism that would interact with the mechanics to release the pawls and integrate in with the glove interface. Lyndon went through several trials of different release mechanism designs and finally came up with the tubular casing design. He built a plastic casing that Kevlar string ran through and attached to the pawls for release. The opposing ends were then attached to the glove at specific joint segments. By pulling on the individually marked release strings, the user is capable of releasing the grip created by the ratcheting mechanics.


9 Conclusion

With the prevalence of stroke and its related effects in today’s society, there is a great demand for devices which improve the quality of life of these affected individuals. Specifically, stroke leaves many people with decreased mobility, dexterity, and hand strength, making everyday tasks difficult to accomplish. Simple activities often overlooked on a day to day basis such as sweeping the floor or holding a hammer, become difficult tasks when grip strength has dramatically decreased.

It is for these very reasons that the Human Integrated Gripping Device has been designed. This device allows the user to regain normal, daily activity without a second thought. By combining a ratchet mechanism into a glove, the user can slip the device on when is needed, perform the task at hand, use the simple release mechanism to disengage his grip, and proceed on with his daily life. The device is lightweight and compact, making it comfortable for the user to wear and easy for him to store. Because of the superior material selection, design specifications and manufacturing of the Human Integrated Gripping Device, the user will enjoy years of new found freedom in his everyday life. It was through this rigorous research, design, development, and testing, that the Human Integrated Gripping Device has been such as success. Hopefully in years to come many more people will be able to experience the benefits of assisted gripping.
10 References


11 Acknowledgements

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Chris Leibler
David Kaputa
Christian Davis
Dr. Martin Fox
Aaron Hills
12 Appendix

12.1 Updated Specifications

Mechanical Parameters
Durability. withstand a minimum of 25 lb-ft force on ratchet
Weight. less than 2 lbs
Materials.
  - Ratchets. Blue Tempered Shim Stock
  - Springs. Spring Steel
  - Rings. Stainless Steel
  - Release Mechanism. Plastic Tubing, Kevlar String
  - Inner Glove. Cotton
  - Outer Glove. Polyester Blend
  - Miscellaneous. Gorilla glue, duct tape, nylon fishing line

Tensile Strengths.
  - String. 20 lb nylon string
  - Metal. min 25 lb-ft

Size
Ratchets. 1"x ½"
Glove Size. extra large
Finger Diameter Range. 5/16” x 9/16”

Environment
Location. Indoor/Outdoor
Dust. withstand dirt, sand
Operating Temp. 32 F – 110 F
Storage Temp. 50 F – 70 F
Moisture. corrosion resistant

Budget
Total Allowable Expenditure. $750
12.2 User Measurements
12.3 Prototype Design
12.4 Finished Prototype Design
Contact Information:

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