DESIGN OF A MULTIPLE FINGER PROSTHETIC HAND WITH A PASSIVE ADAPTIVE GRASP SYSTEM

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ELECTRICAL AND BIOMEDICAL ENGINEERING DESIGN PROJECT (4BI6)

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ELECTRICAL AND BIOMEDICAL ENGINEERING PROJECT REPORT
SUBMITTED IN PARTIAL FULFILLMENT OF THE DEGREE OF B. ENGINEERING

MCMASTER UNIVERSITY

HAMILTON, ONTARIO, CANADA

APRIL 23, 2010

ABSTRACT

Hand amputation is an extremely traumatic experience for a patient; it has been observed that patients that experience the loss of a limb have developed mental and emotional disorders. In order to improve the overall quality of life for hand amputee patients, a number of prosthetic devices are available on the market today. Many of these devices fail to approach the level of dexterity possible of the human hand. Presented in this paper is the design of a prosthetic hand prototype that attempts to duplicate some of the high dexterity of the human hand. Using an adaptive grasp system and an innovative finger link design, the natural appearance and motion characteristic of the human hand were modeled as closely as possible. Coupling this prosthetic prototype to an electromyogram setup and muscle signal classification software, it is our hope that we can control the prosthetic hand using the remaining muscles in the forearm. Enabling a more seamless transition and rehabilitation for hand amputee patients; effectively improving their overall quality of life and mental state.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my parents Javed and Shohreh Bhatti for their endless love and support throughout my university career. Without their support and guidance, I do not think I would have made it through undergraduate engineering.

Next I would like to thank my design project group members Philip Chrapka and Phil Kinsman. Their seemingly endless source of enthusiasm and intelligence made this project a reality. Without the Phil's, this project would not have ever left the drawing board, I am truly in debt to their hard work and in awe of their talents. I would also like to thank Phil Kinsman's older brother, Matt Kinsman who selflessly donated his time to help guide the design of, and eventually fabricate the first prototype of the prosthetic hand.

I would like to thank Dr. Sirouspour and Dr. Doyle for their supervision of this design project.

Finally I would like to thank all my friends in both the Biomedical class of 2010 and within my own personal life, each one of you has in some way shaped the person I have become today and for that, I thank you. Your support, camaraderie and all the good times shared are memories I shall cherish for the rest of my life.

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1. INTRODUCTION

1.1 BACKGROUND

Mutilating hand injuries have been shown to result in stress and anxiety disorders, major depression, pain syndromes and adjustment problems. It has been found that up to 94% of the individuals with a severe hand injury experience symptoms associated with one of these disorders. Their symptoms commonly include; nightmares, flashback memories, mood swings, cognitive difficulties, concerns regarding disfigurement, phantom limb sensation and the fear of dying.[1] It is obvious that losing a hand in an accident is severely traumatic for a person, and can negatively affect their self image which will be directly disruptive of their overall enjoyment of life. In cases where hand replantation is not possible due to the extent of injury, the patient must consider the possibile use of a hand prosthesis in order to be able to return to some of their normal activities with greater dexterity.

The human hand itself is extremely difficult to model; when attempting to duplicate the high dexterity of actions it can perform, one truly learns to appreciate the subtle complexities of human structure. The internal bone structure of the human hand and finger are constructed in a segmented pattern as shown in *fig 1.1*; the proximal, intermediate and distal phalanges in the finger, and the metacarpals within the palm. These bones have a system of tendons that connect to the base of each of the phalanges which serve to curl the fingers to form a hand gesture. The digitorum superficialis and profundus tendons, seen in *fig 1.2*, are connected from the base of the phalanges to the flexor digitorum muscles in the upper forearm. When in contraction this muscle will pull on the

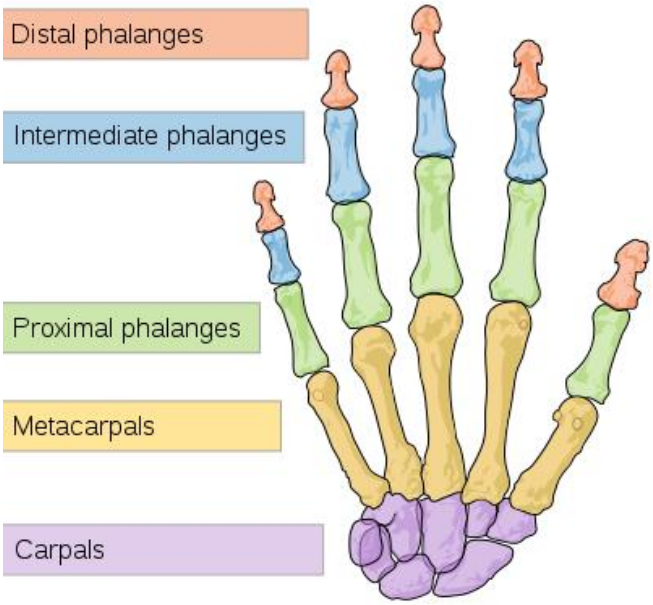


Fig 1.1: Bone structure of hand [2]

tendons, which in turn will curl the fingers. These muscles will be unaffected during a hand amputation and the nerve enervation pathways will remain intact; meaning that the patient will still be able to contract the flexor digitorum normally. As the muscle will still react when the brain commands it too, ElectroMyoGram (EMG) signals can be extracted from this muscle, and potentially be used to control a prosthetic device in order to allow the user to feel like they have more natural, instinctive control over their prosthetic. The full range of dexterity available in the human hand from an engineering viewpoint is amazing; each of the phalange joints acts as an independent revolute joint as each is controlled by its own flexor digitorum muscle in the forearm. At the knuckle, the joint between the metacarpal bones and the proximal phalanges is similar to a limited range ball and socket joint as the lumbrical muscles in between each of the fingers provide limited adduction and abduction of the fingers. These muscles in a hand amputation would be lost in the procedure, but the nerve pathways could potentially be saved and routed to allow for a EMG signals to be taken from them as well. With the knowledge that a number of nerve control signals can still be monitored after an amputation presents both a challenge and an opportunity to the engineer; to design a prosthetic hand that can replicate the dexterity of the human hand, then use the acquired EMG signals to control it.

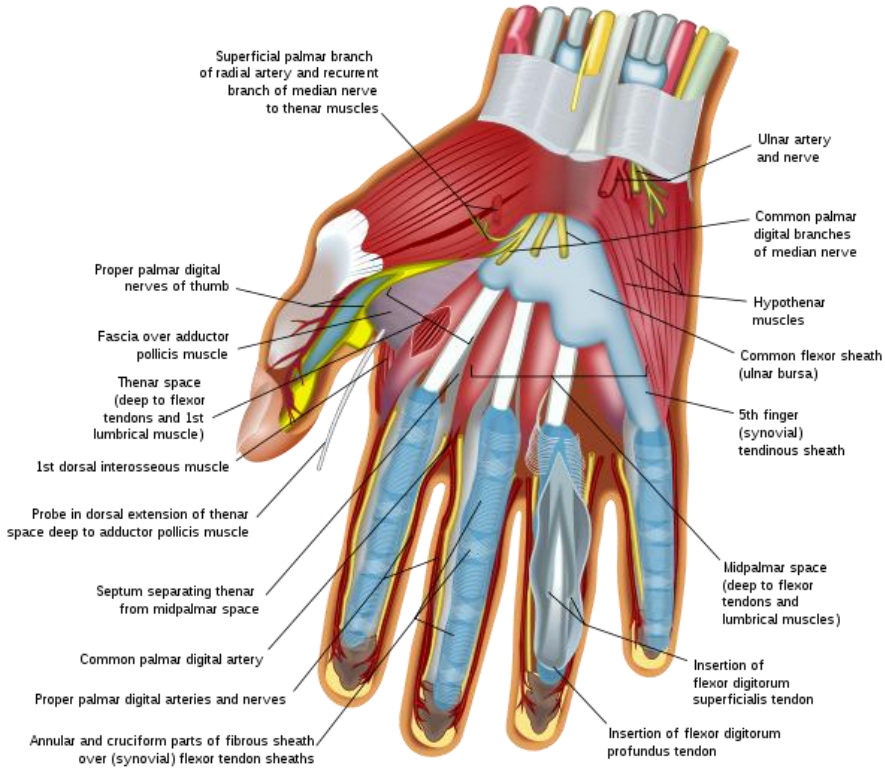


Fig 1.2: Virtual dissection of palmar region of hand displaying tendon and muscular network [2]

This sort of nervous system control would be greatly beneficial for a patient faced with the prospect of losing their hand. Despite the other cosmetic issues, the knowledge that a prosthetic is available which will allow them to recover, even artificially, the function of their

hand will improve their state of mind. This will in turn improve their quality of life, which is ultimately the goal of any treatment plan.

1.2 OBJECTIVES

The collaborative objective of this capstone project is to establish a real time motor control system for a prosthetic hand using EMG signals taken from the test subject's arm. This goal has been broken down into three smaller projects which will come together to accomplish this EMG controlled prosthetic.

Firstly, EMG signals need to be detected from the arm, filtered and amplified, this task was given to Phil Kinsman. This task's objective; the acquisition and signal conditioning of the desired muscle enervation signal. The EMG will be detecting the tiny voltage fluctuations of the enervating nerve's action potentials, a voltage change of approximately 110mV at the surface of the nerve. When this voltage is measured from the surface as it has been in this project with a surface electrode, a fair amount of external and biological noise is added to the signal. This will all need to be removed from the signal in order to classify the muscle contraction based on amplitude and frequency of measured action potentials.

The EMG signals are digitized and passed into a classification software to determine whether the recorded signal was a contraction or not and then output a voltage to the motors of the prosthetic hand accordingly. The task of signal classification fell to Phil Chrapka, the objective; to build a software suite for classification of recorded EMG signals. A motor control script was also to be written in order to control the motors of the prosthetic according to the gestures identified by the classification software.

Finally, the design of the prosthesis itself is the subject of this capstone project. The objective is to design a prosthetic hand that could be potentially constructed within the given time constraints. The designed prosthesis would have to be able to mimic as much of the complex dexterity of the hand as possible. The amount of potential dexterity of the prosthesis is initially dependent on the acquisition system; the more muscles that are monitored and recorded, the more potential movements that could be mimicked by the prosthesis. As the system is

constrained by the number of EMG control inputs it has to determine the desired prosthesis hand gesture. Following the constraint of control input, the dexterity of the designed prosthesis has been limited to fit within the scope of the design project which is defined below in section 1.4.

1.3 METHODOLOGY

The design of the hand prosthesis began with a literary search in order to learn about current and future designs of hand prosthetics. Following the collection of ideas and inspiration, a number of initial designs were drafted in the project journal. Each of the initial designs carried some portion that was inspired by the literary search, but the goal of each design was an attempt to closely model the motions of the hand. It was during this drafting stage that many decisions were made concerning the final form and function of the prosthesis. This design was then constructed in the Computer Aided Design software, Solid Edge; which allowed for dimensional and motion analysis of the prosthesis. Although the parts were designed initially on paper, once in the CAD software exact dimensions were assigned to each part, and motion analysis ensured the natural appearance of the prosthetic's motion trajectory. Once the prosthesis design had been finalized, it was given to Matt Kinsman, who machined and constructed the very first prototype of the prosthesis.

1.4 SCOPE

To design for a relatively simplistic prosthetic hand in order accurately mimic just a few of the motions possible with the human hand. It would be difficult and beyond necessity to design a highly complex prosthesis that would mimic all the gestures possible by the hand. However for the chosen articulations of the hand, the prosthesis must be designed to allow these articulations appear as natural as possible. Taking also into consideration the necessary robust design as the prosthesis would potentially be used in everyday life, it would need to be designed for strength, stability of motion and durability of parts. The parts designed would also need to be designed in a way to allow for simple machining and not require overly complex machine work

to construct. The construction of the hand prosthesis prototype would be done by Phil Kinsman's brother Matt Kinsman as a favour, so the parts needed to be simple to machine, as Matt, also a busy student, his free time was precious commodity.

Initially the scope of the project included the actuation of 6 different gestures, which would require a hand that could curl/extend its fingers for the first 2 gestures. A 2 degree of freedom wrist joint to mimic the pronation/supination and curling/extending of the wrist joint was required for the last 4 gestures. Over the course of the year the scope of the project was narrowed from its slightly over ambitious beginnings to focus on solely the first 2 gestures; curling and extending the fingers, and ensuring that these actions were emulated in the prosthesis as accurately as possible.

2. LITERATURE REVIEW

2.1: *THE DESIGN OF ANTHROPOMORPHIC PROSTHETIC HANDS: A STUDY OF THE SOUTHAMPTON HAND* [3]

PETER J. KYBERD, COLIN LIGHT, PAUL H. CHAPPELL ET AL.

The current problem with most available prosthesis is that they lack the ability to accurate replicate the dexterity of the natural hand. In the hand there are 19 joints alone, each with a network of individual muscles allowing for fine motion and in some cases multiple degrees of freedom. The two principle postures of the hand have been defined as, *Precision*; where the tips of the fingers oppose the tip of thumb and *Power*; where the thumb opposes the palm area. If a more natural prosthesis is to be constructed, it would need to achieve these two hand postures in order to allow for the greatest amount of mobility.

Powering a prosthetic in order to provide a high level of portability, allowing the user to feel unburdened by the need for an external power supply, have conventionally had two forms, body power and electric actuation. Body power is provided to the prosthesis device, with a harness that is attached around two parts of the body, and their relative motion will pull on the harness and actuate the device. In most cases for below elbow amputations the prosthesis harness will be attached across the back, so that scapular motions will manipulate the prosthesis end effector. Scapular abduction will open the hand, and the reverse motion, scapular adduction, will close the hand. The motion connectivity allows for a mechanical feedback system for force applied by prosthesis hand grip, as the user will be able to feel the tension applied through the harness linkage. This method of control allows the user to operate a single degree of freedom at a time, seriously limiting their ability to complete any dexterous motions while gripping an object. This method does provide some assistance for users, although the lack of free motion while gripping an object will make it more difficult for the user to adapt to life with this type of prosthesis. Electrical actuation is the most practical external power source for a hand prosthesis, as no other modalities provide the same amount of effective power in a compact form. An

electrically powered prosthesis is instructed to open and close deliberately by the operator and can hold its position, making a combination of dexterous movements a possibility.

The Southampton hand, developed at the Southampton University in its most recent version has been a fully anthropomorphic five fingered hand with digits that curl completely from fully extended. The thumb can move in two directions; flex/extend and abduct/adduct. The index finger is individually driven, allowing for fine grip between the thumb and index finger. There are DC motors attached to a cable drive system which is responsible for curling the fingers; the cables act as tendons exerting tension on each of the joints in the fingers. The drive system for the other three fingers on the hand is particularly unique; in order to curl the other three fingers together on a single drive cable and maintain form of adaptive grasp. An equalization mechanism called a whiffle tree was used, which enabled the fingers to balance the out the force on an object between them, effectively an adaptive grasp system. This drive design has been illustrated in *figure 2.1*; finger 2 would be the index finger, and finger 3, 4, and 5 would be the remaining fingers, middle through pinky. The fingers are designed to provide continuous smooth curling motion; as such each of the phalanges is individually articulated. The control system of the Southampton hand enables for both mechanical and electrical adaptability; mechanical through the Whiffle tree equalization mechanism. Electrical control adaptability is achieved from the individual control of the index finger from the other three fingers separately.

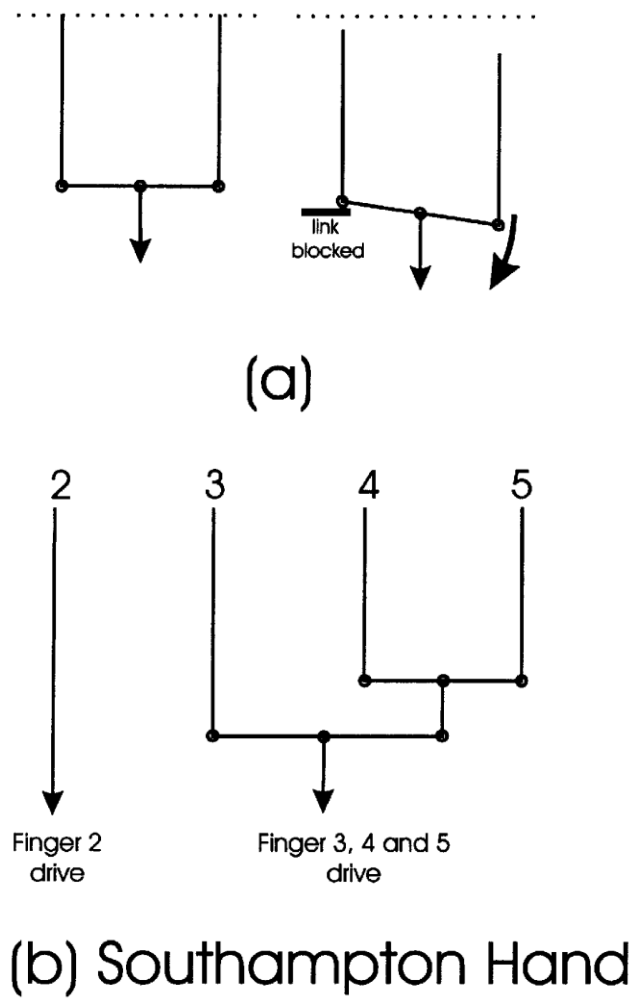


Fig 2.1a: The Whiffle tree mechanism, an equalising linkage that allows multiple lines to be actuated by the same drive without one being impeded by another being stopped.
Fig 2.1b: Southampton Hand design, simplified drive linkage. [3]

The concept of this design is an extremely well developed solution to the problem of developing a dexterous finger that can provide a precise grip and strength, with a drive system that allows for the module to compact enough to between within reasonable bounds. The construction of such a design however would prove to be very difficult, due to the complex nature of the design. It would be very time consuming to accurately reconstruct a CAD representation of the design in order for analysis of its motion, and eventually its machining.

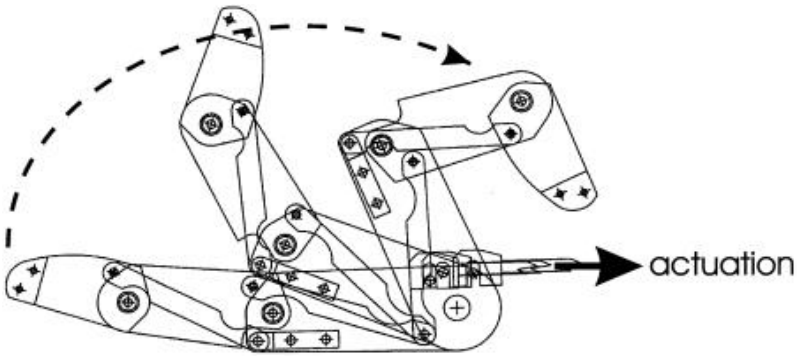


Fig 2.2: Design of interphalangeal linkages that allow for the digits to curl progressively from fully flexed to full extended. [3]

2.2: *Design and Prototyping of an Active Hand Prosthetic Device* [4]

Jingzhou Yang, Karim Abdel-Malek and Jason Potratz

This paper contains an interesting solution to mimic the some of the complex motion of the human hand. The IOWA hand is composed of five active fingers each capable of bending at all three phalangeal joints, offering a full 15 degrees of freedom for the entire hand. The design of the IOWA hand is suck that each of the fingers is comprised of a number of compression springs, compression links, cables and conduits. With each of the springs acting as a joint, an tension force placed on the drive cable will lead to deformation of the springs and collaborative curl the finger. Extension of the fingers each of the fingers can be achieved with the inherent properties of the springs as once the tension of the drive cables is released, they will return to their natural positions.

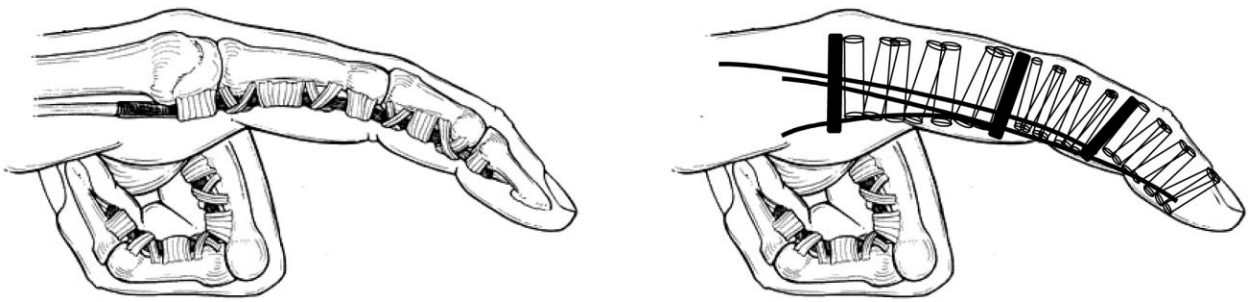


Fig 2.3: Comparing tendon linkage of the human hand(right) to the linkage design of the IOWA hand(left), it is clear to see that the cable linkage has been inspired directly by it biological equivalent. [4]

The implementation of springs to form the structure of the fingers enabled the hand to be built light and generally mouldable to any object in its grasp. This offers an advantage over many exoskeleton models that are generally feature stiff finger links, which usually are unable to mould their grip around an object. Testing this design would need a fairly complex experimental setup as the springs are very difficult to model in CAD software in the amount of time available for this capstone project. In this paper, extensive testing was conducted to map and predict the motion of the springs in order to choose the desired mechanical properties of the spring that would meet the constraints that they had originally defined for the IOWA hand. For the first

version of the IOWA hand a 161-node and 160-element finite element model was developed to evaluate the deflection of the spring under three different loading conditions with a single cable actuating the joint. Then again with multiple loads and multiple cables actuating a spring joint with, this enabled testing of the multiple degrees of freedom that the spring joint could offer. Next a Haringx element model; a model consisting of small elements that are essentially ordinary linear springs, was created to analyze a number of forces present in the spring during deflection. Further analysis was done with an element stiffness model in order to model linear load-deformation for a small element within the helical spring. Basically an element map of spring was created and its deformation was modelled in relation to a number of loading axis's.

The development involved in this potential solution for the prosthetic hand is far beyond the scope of this project. A mechanically actuated finger linkage is still favoured due to the fact it will have fewer degrees of freedom than a spring finger linkage. Therefore reducing the amount of developmental planning involved in creation.

Fig 2.4: Final constructed IOWA hand(left) and a demonstration of the IOWA hand's power grip gesture holding a baseball(right) [4]

2.3: *MULTIPLE FINGER, PASSIVE ADAPTIVE GRASP PROSTHETIC HAND* [5]

N. DECHEV, W.L. CLEGHORN, S.NAUMANN

This paper details and discusses the design and development of the TBM prosthetic hand (Toronto/Bloorview/MacMillan). The intended design goals of this prosthetic hand were to minimize the amount of pre-orientation required by the user, and to improve upon the overall cosmetic appearance of the prosthesis. This prototype prosthesis incorporates a system that gives its four fingers and thumb, the ability to independently conform to the shape of an object in its grasp; the adaptive grasp system. There are three features of the hand that allow for adaptive grasp, firstly the finger are able to curl during flexion, giving the prosthetic finger flexion characteristics similar to the human hand. Secondly, the fingers are able to flex independently of each other during closing, with the use of a parallel spring mechanism within the palm. Finally, the thumb is able to adduct (rotate inwards) and abduct (rotate outwards) as well as to flex and extend.

The primary goal in designing the fingers was to make the fingers appear as natural as possible in both appearance and motion characteristics. Modelling directly from a human finger, three segments make up the prosthetic finger for a total of six links. Links 1, 2, and 3 correspond to the three segments of the human finger and have been dimensioned to be the same size as the average human finger. Whereas link 4, 5, and 6 are the connecting joints that drive the curling

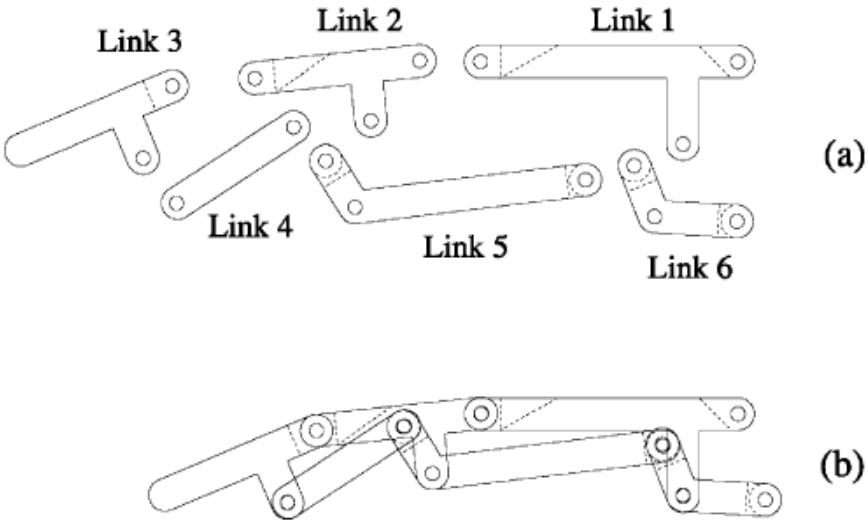


Fig 2.5a: Disassembled finger, side view displays the basic construction of each link
Fig 2.5b: Assembled finger displaying the manner in which the separate linkage fit together [5]

motion of each finger. At link 6, the end linkage is attached to the linear actuator that will pull on the finger and curl the finger. The curling trajectory has been as design to be as universally adaptable as possible, along with the adaptive grasp system, a large variety object can be held with the fingers.

A form of independent flexion of the fingers is achieved through the adaptive grasp system. During finger flexion, each finger will flex around an object, however, the final position of each finger will be relative to the others based on the shape of the object in its grasp. The design that allows for adaptive grasp is a piston system; all of the fingers are acted upon by a single linear actuator connected to a force plate. The force plate is then connected to a set of four pistons (cylinder springs); a piston per finger, the end of each finger is then connected to the end

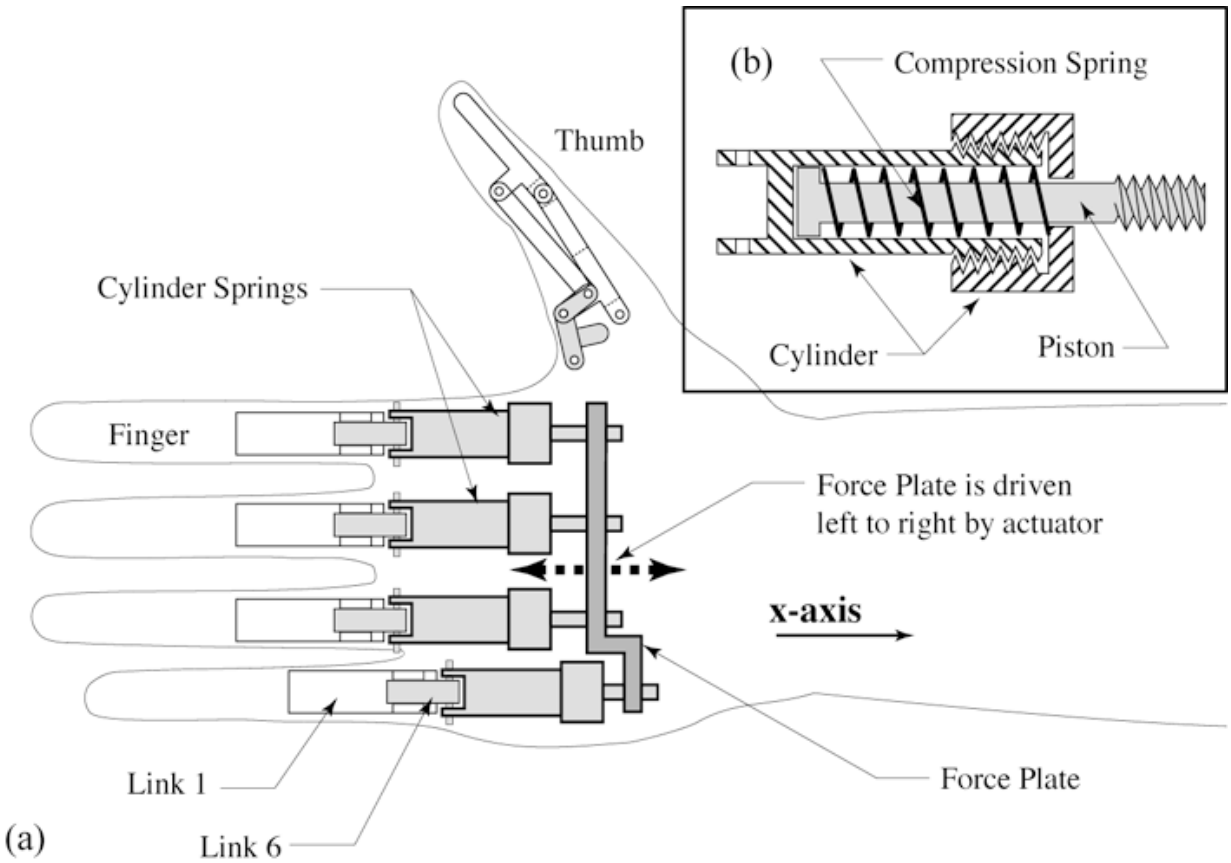


Fig 2.6a: Adaptive finger design, offset force plate design allows for pinky finger to set lower than the other fingers, mimicking the exact structure of the human hand.
Fig 2.6b: Cylinder spring design, cylinder length is designed such that the spring is slightly in compression, creating a threshold force to overcome before the spring will begin to compress. [5]

of link 6 on each finger. When the force plate is forced downwards by the linear actuator the fingers begin to follow their natural curling motion until they become obstructed by the object in its grasp. At this point the spring in the piston's initial compressive force will be overcome and begin to compress. The unobstructed fingers will continue to follow along their natural path until they too become obstructed by the object in its grasp. Meanwhile, the fingers that came into contact with the object initially will tighten their grip around the object relative to the stiffness coefficient and amount of compression of the piston spring. This unique design overcomes the potential for imbalance in the grip and stabilizes the grip ensuring that the object will be grasped securely.

The thumb designed so that it can be actuated with the same linear actuator as the fingers. When design the linkages, the same consideration for biological accuracy was taken into account. The thumb is constructed with four links; two links that make up two segments mimicking the human thumb, and two links that connect the first two links together and are responsible for curling the thumb. Flexion of the thumb is achieved with a drive cable connected between the final link of the assembly and the force plate. Whereas extension is achieved with an extension spring positioned against a flange on the final link which will extend the thumb when tension on the drive cable is released.

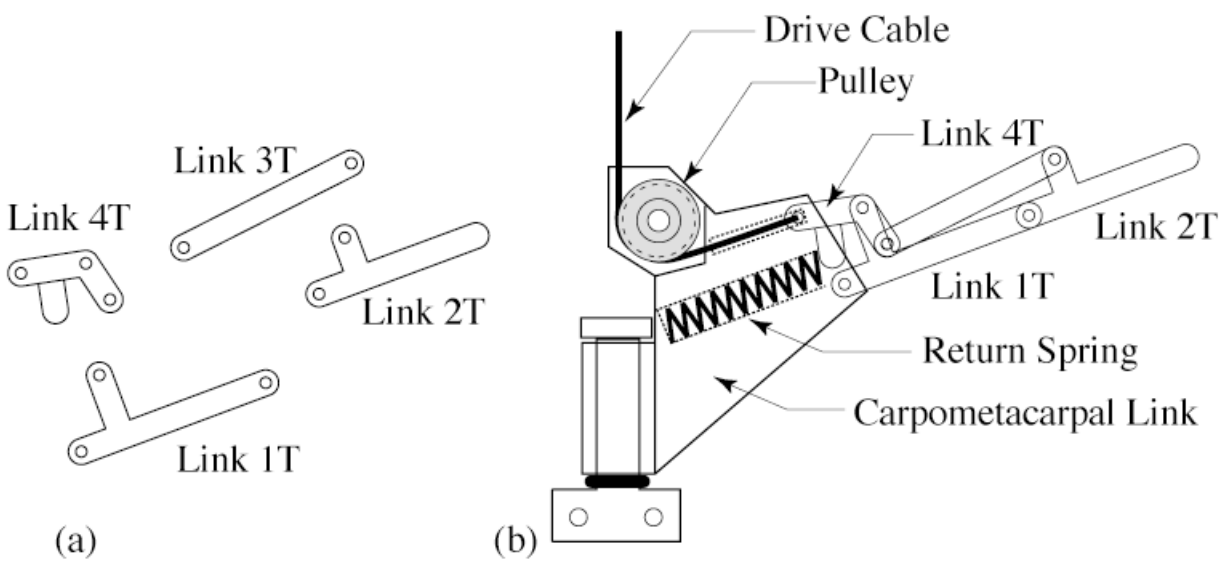


Fig 2.7a: Disassembled side view of thumb linkages
Fig 2.7b: Side view of full thumb assembly, showing extension spring and drive cable linkage [5]

The overall design of the TBM is unique and allows for a great amount of dexterity and grip adaptability. Replicating such a design for this design project is within its scope, as the design goals for the TBM hand are parallel with this design project. The finger link design will have to be adapted for easier machining and a palm will need to be designed to complement the fingers and thumb and allow for the adaptive grasp design to be incorporated into the prosthetic hand.

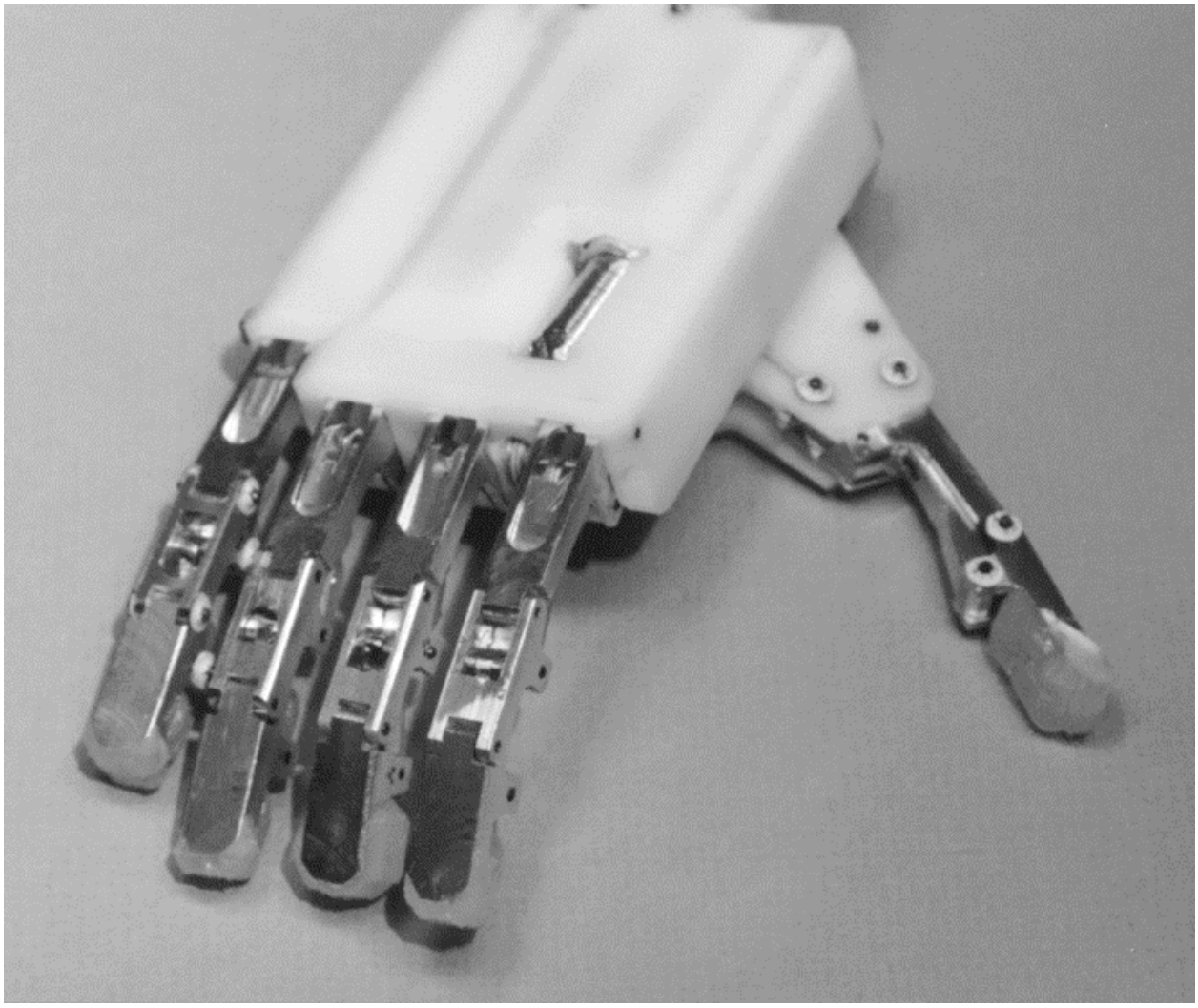


Fig 2.8: Full assembly of TBM hand prosthesis prototype [5]

3. STATEMENT OF PROBLEM

The goal of this capstone design project is the design of a prosthetic hand that as close to the human hand in both appearance and motion characteristics. It is to have similar grip abilities to the human hand and is to implement an adaptive grasp system[5]. The components and linkages in the hand must be designed with the manufacturing process in mind, as each part will eventually be machined in order to construct a final prototype for a project demonstration. The dimensions of the final designed prosthesis must be approximately the size of the human hand, in order to maintain its natural appearance. Although it will be a mechanical model, it is common that a moulded glove is fit over the prosthesis which gives it the natural appearance of the human hand.[5] As such, the focus of this capstone project is essentially the design of an end effector to be driven by the motor control signals being sent from the muscle signal classification software.

4. METHODOLOGY OF SOLUTION

To approach the design of this hand prosthetic, a design was chosen from the literature study and extensive work was done to adapt and improve the design to fit the scope of this capstone design project. The chosen design was the TBM hand prosthesis[5]; this design had many of the desired properties and the paper provided enough detail in order for further design progress to be made.

The initial design for all the pieces of the prosthetic was drafted on paper and some sample dimensions were assigned to the parts in order to give a idea of scale when designing each of the parts relative to each other. Next, the machinist that was to assist in the fabrication and construction of the prototype was consulted. A number of changes resulted from this consultation; with the machinist's knowledge of the fabrication process most changes were to change the design of the finger and thumb linkages in order for more precise fabrication. So a second design was drafted and partially dimensioned on paper. This design incorporated many of the ideas that resulted from the consultation with the machinist and a number of improvements. A second consultation with the machinist occurred where the new designs were presented, after a few minor changes, the design was approved. These initial drawings can be seen in appendix section A.1.2. The next major step was creating a virtual model of the prosthetic; this was created in the computer aided design software, Solid Edge. The major challenge was choosing dimensions for all of the parts that ensured that it had the desired motion trajectory. The motion analysis feature in Solid Edge aided this process greatly as the final assembly was analyzed for potential collisions. Then changes to each of the parts could be made and these changes would be instantly applied to the assembly. It also allowed for the thumb and finger to be designed in order for them to meet tip to tip, so that the prosthetic could grasp small objects and hold them between the tips of the fingers and thumb. Next a number of parts were selected from the McMaster-Carr hardware distributor website to be purchased and incorporated into the prototype. The design had to be once again modified in order to accommodate these parts. The design was finalized and a number of drawings were submitted to the machinist, so they could begin fabrication and construction of the first prototype of the prosthetic hand.

5. DESIGN PROCEDURES

5.1 FINGER DESIGN

The goal when constructing the fingers was to replicate the appearance and motion characteristic of the human finger as closely as possible. The basic construction of the finger linkages was inspired by the TBM Hand[5] finger linkages. The design of each of the links underwent a number of minor changes, but there were only two fundamental designs structures variations.

The first design was similar to the TBM Hand [5], it was comprised of six links and was modelled as closely to the human finger as possible. The structure and design of these six links is detailed in appendix section A.1.1; link 1, 2, and 3 are designed to mimic the structure of the distal, intermediate and proximal phalanges. Links 4, 5 and 6 acts as connecting links between links 1, 2 and 3, and they are also responsible for creating a smooth flexion of the fingers. With the end of finger link 3 fixed to the prosthetic palm block, a linear force along the x-axis acted on the end of finger link 6 will force the finger links to curl along the desired trajectory as all other finger joints are passive. During finger flexion, finger links 4, 5 and 6 would slip in between the

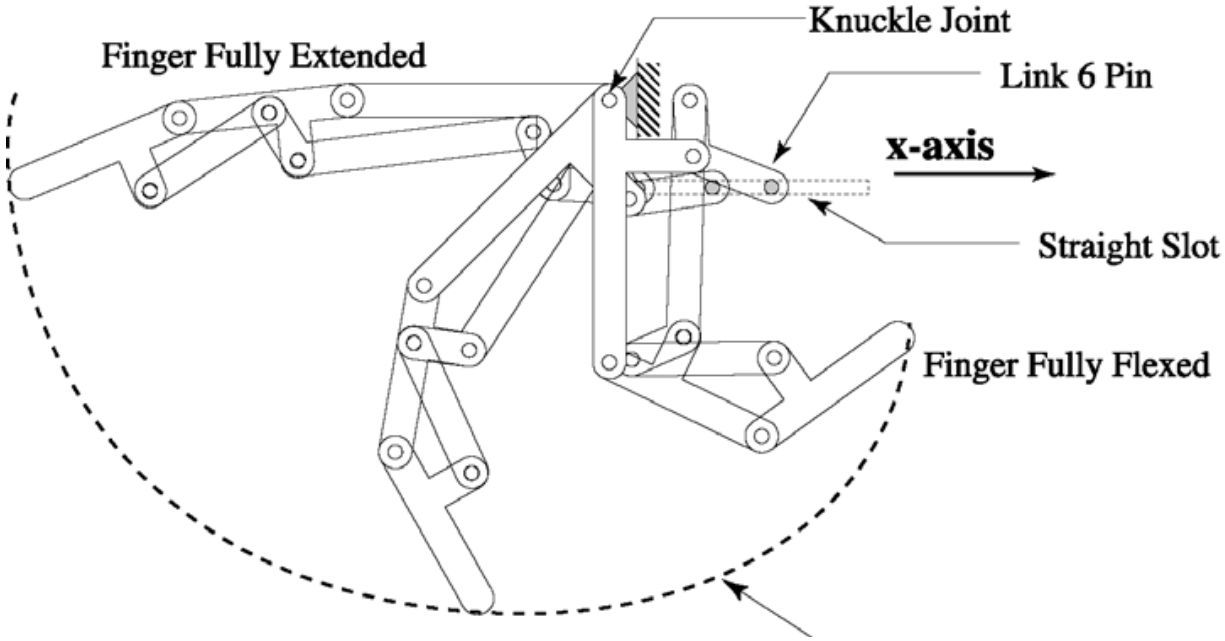


Fig 5.1: Illustration of finger flexion [5]

gaps in finger links 1, 2 and 3 allowing for freedom of motion. Finger extension is achieved just as simply as finger flexion; a reverse force is required along the x-axis in order to extend the finger. Although, after a consultation with the machinist the design was abandoned as it was too difficult to machine precisely. Many of the parts required angled channelling; a difficult process to complete for the relatively small dimensions required by the finger link design.

So a new design was drafted and can be seen in appendix sections A.1.4. With this design the finger linkages would scissor past each other instead of through each other. Finger links 2 and 3 would be arranged to one side and links 4 and 5 on the other, with finger links 1 and 6 spanning both sides anchoring the two linkage arrangements together. This arrangement allowed for the finger links to slide past each other freely achieve the same fingertip trajectory as before except with a simpler link design. This design was then shown to the machinist, who approved of this improved design.

The next major step was choosing dimensions for all the pieces and constructing a virtual model of the finger. The process for choosing the dimensions for the finger linkages was relatively simple in concept but was very labourious in application. Each of the finger segments; links 1, 2, and 3 were given lengths that were the approximate lengths of Shameem's own finger segments. From these three dimensions the rest of the dimensions were derived and extrapolated, then checked with the virtual model to ensure that they achieved the desired finger tip curling trajectory free of collision and obstruction. The assembled finger can been seen in appendix section A.2, which illustrates the manner in which the links would fit together.

This final finger linkage met the desired design objectives, as it closely mimic the human hand appearance and motion characteristic during finger flexion and extension.

5.2 THUMB DESIGN

The goal for thumb linkage design was identical to finger design; a natural appearance and motion characteristic was desired, as well as the ability for the construction of a firm grasp of objects against the fingers. An initial design was created for the thumb based on the TBM hand [5], which was constructed with 4 links and can been seen in appendix section A.1.1. In this

initial design, links 1 and 2 were to mimic the proximal and distal phalanges of the thumb and links 3 and 4 were to connect first links together. Thumb flexion was achieved using the same principle as finger flexion, with the end of link 1 fixed to a thumb plate mounted on the palm, a linear force applied to the end of link 4 would pull the thumb into flexion. The links on the inside of the thumb (3, 4) would fit in between links 1 and 2 during flexion. However for the same reason that finger links need to be redesigned the thumb pieces need to be designed for easier fabrication.

So a new design was drawn up where the links of the thumb would scissor past each other similar to the way the fingers did in flexion. Once the thumb was flexed it was not possible to extend it in the same manner as the fingers, because as shown in appendix section A.1.5, thumb flexion was to cable driven. So if we were to loosen tension in the cable, the thumb would not extend on its own; instead slack would develop in the cable line. Therefore in order to extend the thumb, an extension spring was to be included in the thumb mounting plate that would push against the end of link 4, thereby extending the thumb as soon as tension was released in the drive cable. This design was approved by the machinist and then the design process for the thumb moved forward to be design in Solid Edge. Dimension were taken from Shameem's thumb and applied to link 1 and 2 as represented the phalangeal segments of the thumb. The rest of the dimension were developed relative to the finger and extrapolated from the chosen length of link 1 and 2. The final design of the thumb links and thumb assembly can be seen appendix sections A.2. Motion analysis of the thumb relative to the finger confirmed that the chosen dimensions ensured that when both finger and thumb were flexed by the displacement of their final links, it would take the same amount of displacement in order for them to meet tip on tip. This was an important design consideration as it allows for a more dexterous grip when attempting grip small objects between the prosthetic fingertips.

As mentioned before the thumb was attached to a thumb mount plate. This thumb mount plate was to be attached to the palm block, which will be detailed later, contained the extension spring responsible for extension of the thumb. It also contained some cable routing intended for the drive cable to pass through so it could eventually be connected to the force plate in the palm block.

5.3 ADAPTIVE GRASP SYSTEM / FLEXION DRIVE SYSTEM

The most interesting and unique feature of this prosthetic hand is the adaptive grasp system. Adopted from the TBM hand[5], the adaptive grasp system allows for the fingers to independently conform about an object within its grasp. The main structure of the system is constructed with a force plate and an array of piston springs which connect to the fingers. The initial design and basic theoretical development for this system can been found in appendix section A.1.2.

The system is comprised of three basic components; the force plate, the pistons and the motor drive shafts. The force plate simply a long rectangular piece of aluminum to which each of the pistons will be attached. The motor drive shaft is threaded bolt, when driven by the motor it will make the force plate translate along the drive shaft's main axis. Thereby either pushing or pulling on the attached piston springs. The design of this system can be seen in appendix section A.2. The piston spring is the heart of the adaptive grasp system, an assembly of the piston spring can be seen in appendix section A.2, and below in fig 5.2.

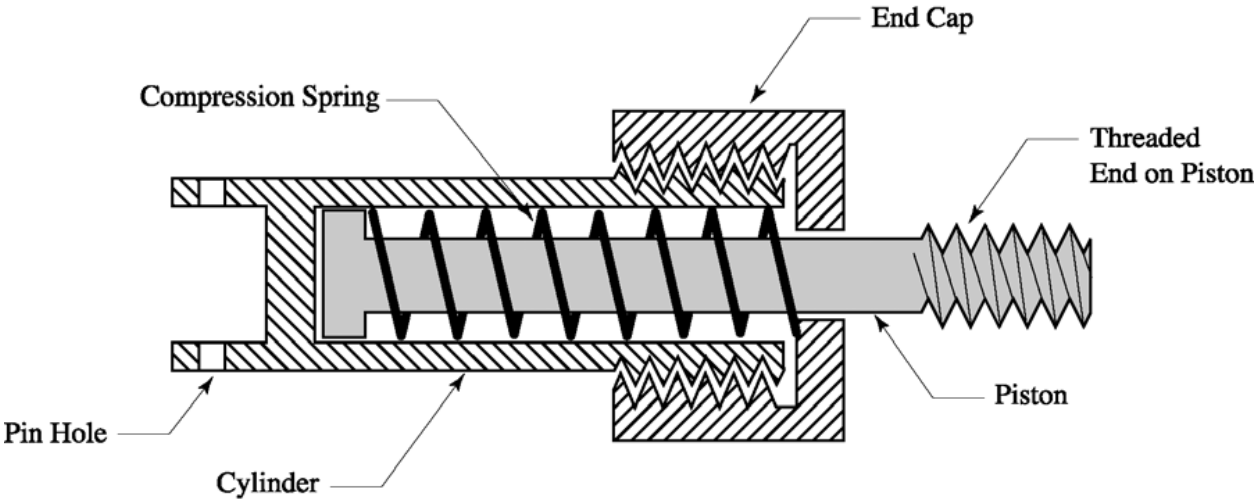


Fig 5.2: Cross-sectional illustration of piston spring [5]

The pin hole will connect to the end of link 6 of the finger and threaded end would connect to the force plate creating a connection for the transfer of motion between the two components. However, the design of the piston spring is such that as the finger are being curled should one of the fingers become obstructed by an object in its path, the force plate can continue along its

motion path curling the other unobstructed fingers. Meanwhile the obstructed finger will be pressed against the object and instead the spring inside the piston spring will be compressed with the continued motion of the force plate. This effectively will tighten the grip around the object until all of the fingers have reached their maximum flex points or they have conformed around the object forming a stable, conformed grasp. This concept is illustrated below in fig 5.3.

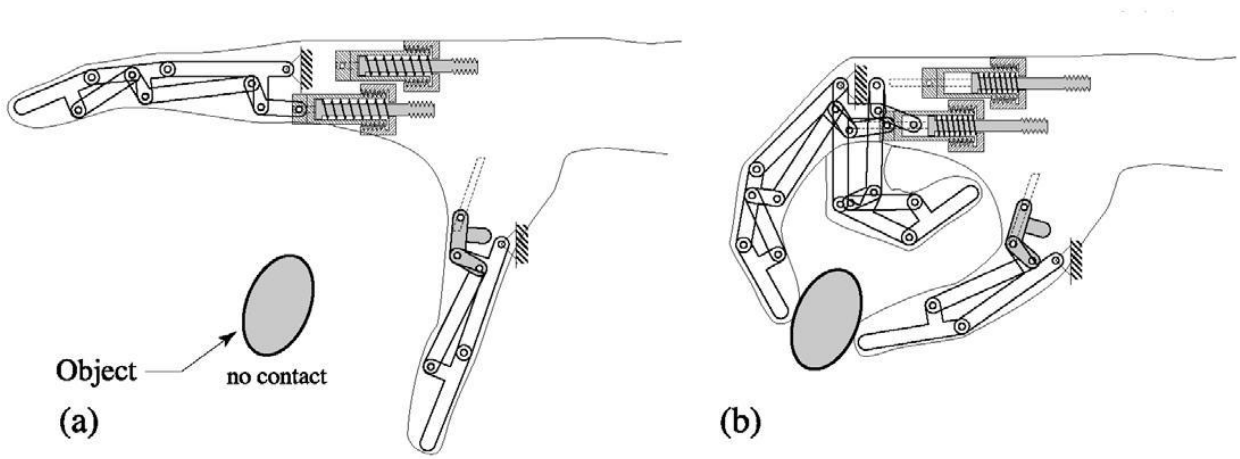


Fig 5.3a: Fingers and thumb fully extended and piston springs are fully extended as fingers are not obstructed by objects
Fig 5.3b: As fingers and thumb curl to close around object one of the fingers comes in contact with the object while the in obstructed fingers continue along their curl trajectory. Note that the spring has begun to compress and exert a force on the object proportional to the stiffness value of the spring. [5]

The drive system of the prosthetic hand is composed of two DC rotary motors, each with a threaded bolt fixed to their drive shaft. The two motors spin in unison to allow for even translational motion of the force plate and allow for a high grip force to be achieved. When the force plate is driven in the opposite direction, in order to extend the fingers, the piston will be forced against the end of the piston spring cylinder and will allow for extension of the fingers.

With the application of this design in our prosthetic prototype, many grip types and shapes can be achieved allowing for much high dexterity than most simple grip prosthesis. This system fulfils the design requirement that the hand be able to mimic the dexterous grip of the human hand.

5.4 PALM BLOCK DESIGN

Once all the other components; finger and thumb linkages and adaptive grasp framework, had been design. A palm block had to be designed in order to house the piston springs and force plate and mount the thumb and fingers. The palm was design essentially from scratch, a frame was first built around the piston springs and the force plate. The initial designs can be seen in appendix sections A.1.3 and A.1.6. Eventually the palm block was expanded to accommodate for the translational motion of the force plate and mounting of DC motors to the base. Next mounts need to be created for the fingers, initially the palm had an internal bore, originating from the open area in the palm of the block, to accommodate for the piston springs and the mounts were placed on the outside of the palm block. After one of the consultation with the machinist, he suggested that the bore be made from the outside of the palm and the required mounts for the fingers simply be constructed with a mountable face plate to go onto the end of the palm block. This final design can be seen in appendix A.2, where the finger mounting plate is attached to the end of the palm block after the piston spring holes have been bored out. In this diagram it is also possible to see the manner in which the motors are to be mounted.

6. RESULTS AND DISCUSSION

Once the plans had been submitted to the machinist, the fabrication and construction process was essentially out of our hands. Most unfortunately, during the time that the machinist had allotted to assist us in the fabrication of a prototype, his wife gave birth to their second child. This understandably put a heavy constraint on the amount of time he could spend on the fabrication of the prototype. In the end, he was able to assist us in constructing three full fingers and a rudimentary palm block with a direct drive force plate system. The final product is pictured below in figure 6.1. The only elements of my design were the fingers in this prototype and they worked exactly as predicted. They had the overall structural appearance and exhibited the desired motion characteristics to model the human hand effectively.

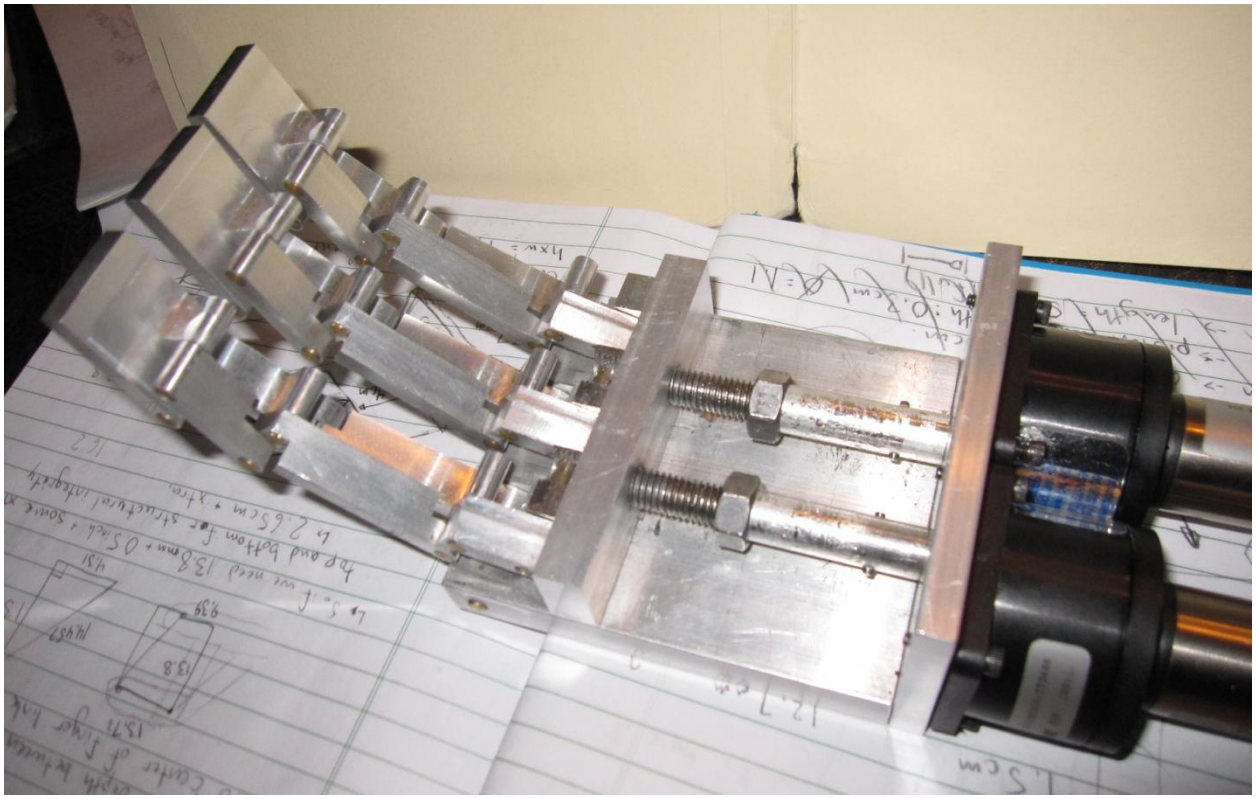
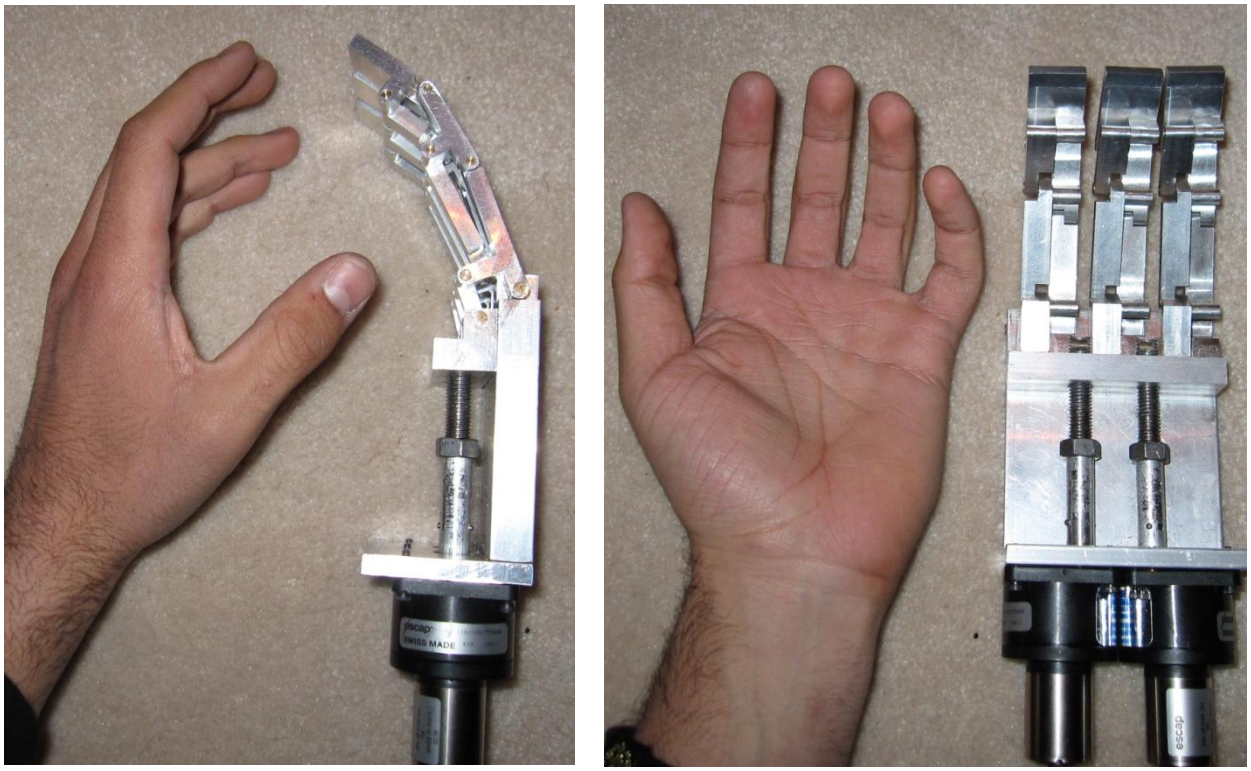


Fig 6.1: Prosthesis prototype model with a direct drive force plate from the motor drive shafts.



Figs 6.2 a and b: Comparison of prosthetic prototype to human hand. Notice the near exact sizing of the prosthetic finger segments to the human hand, as was designed.

We were able to test this prototype on demonstration day in coordination with the other components of the project. When the muscles being monitored by the EMG system were flexed, the fingers of the prosthetic began to close along the finger curling trajectory at a reasonable speed. When the muscles were relaxed, the motor control unit switched the voltage polarity and the fingers began to extend until they reached their maximum extension point. However there were some inefficiencies within the model that did not allow for the fingers to curl at a faster rate. Due to the rushed fabrication the drive shaft spindles and the bore holes in the force plate were not aligned properly and had a tendency to become stuck. Another problem that arose was that although both motors were powered with the exact same voltage, they did not spin at the exact same rate. This resulted in the force plate being pushed or pulled on one side faster than the other, which ended up in misaligning the force plate. This created a high mechanical resistance which the motors could not overcome and the prosthetic finger would become stuck until balance was restored in the lead screws.

7. CONCLUSIONS & RECOMMENDATIONS

The objective of this design project was to create a hand prosthesis that accurately replicated the appearance and motion characteristics of the human hand. The prosthesis was then expected to be able to interface with the output of the EMG signal classification system in order to control the motors that curl the fingers.

The prosthesis prototype was never fully completed, but enough of the model was built to accurately conclude that the design for the finger linkages was an effective model of both the appearance and motion characteristics of a human hand. When interfaced with the other systems the prototype operated as expected and followed the output signal of the EMG signal classification system. As it stands the prototype built demonstrates a proof of concept that it is possible to construct a prosthetic hand that could mimic the complex curling motion of the human hand.

In the future, if such a project were to be undertaken again, it would be vital to ensure that meetings with the machinist are held regularly during the design process. As in the case of this project, a meeting was held near the end of the second term, so a number of major changes need to be completed to the design in a short amount of time. This ultimately resulted in the partial completion of the prototype as time constraints became the limiting factor.

APPENDIX

A.1.1 – ORIGINAL FINGER AND THUMB LINK DESIGN

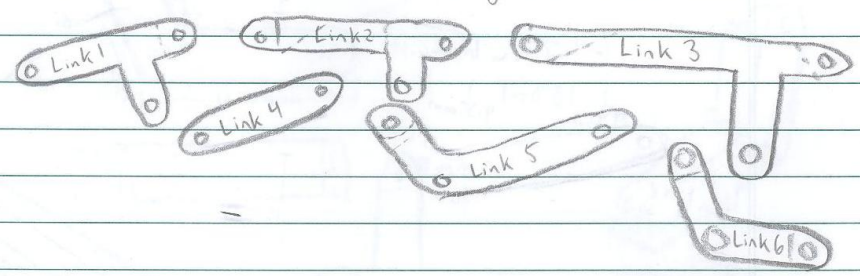
Design of Prosthetic Hand Oct 26th

Design Considerations.

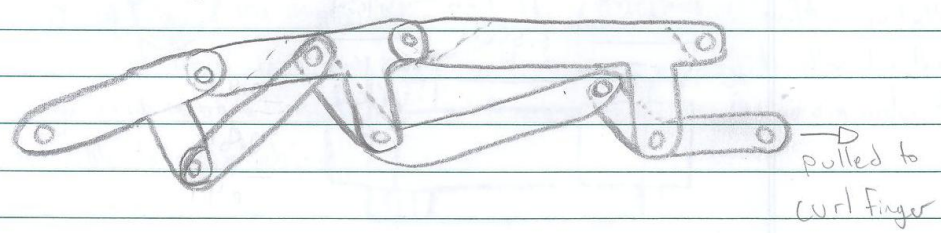
- Due to the objective of this project being the actuation of a prosthetic hand with the measured/active EMG signals. The focus lies more on the control of the hand. It is for this reason the design of the hand is to be adapted from previous sucessfull design to create a design that will meet the criteria set initially for this project.
- Design of the hand is to be modelled as closely to a human hand as possible:
  - fingers curl as they close.
  - an adaptive grasp, fingers can close independant of the others when gripping an object.
- A mechanical design for the fingers was chosen due to the relative simplistic nature of it's construction, as it will be easy to construct a prototype will relatively few mechanical complexities.

Finger design: taken in part from N. Dechev et. al / Machine and Machine Theory

Side profile of Disassembled finger

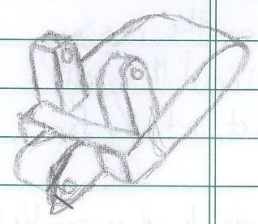


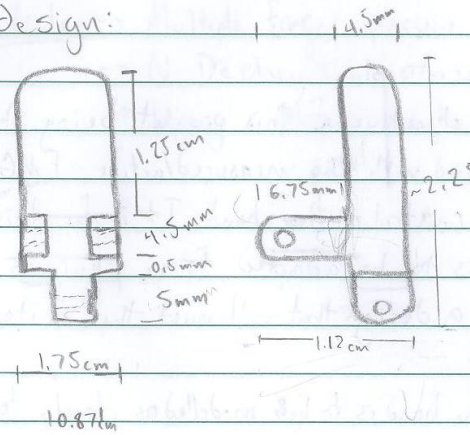
Assembled finger



Link design:

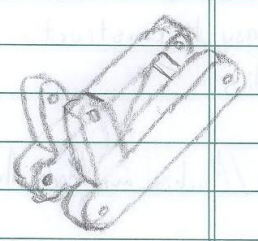
Link 1:

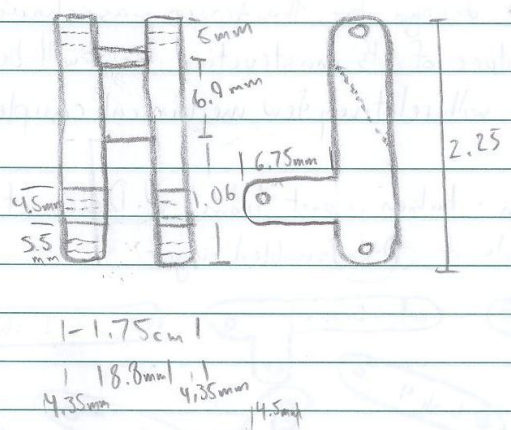




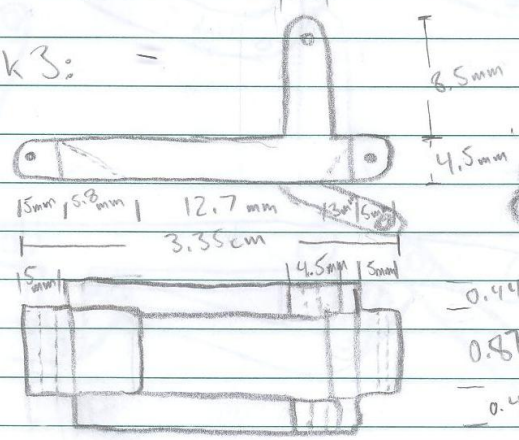
Proposed Dimensions:
- hole size to be determined by pin size
- hole placment to be determined once parts are found to fit together.

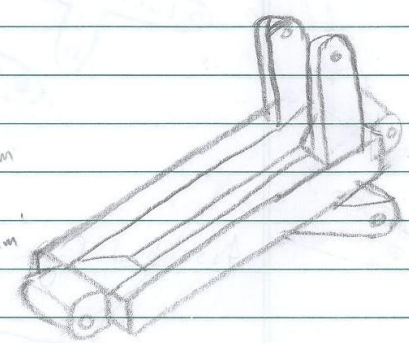
Link 2: Similar in design and dimensions to Link 1 except for an opening at the back to allow for freedom of motion for the joint of Links 4 and 5.



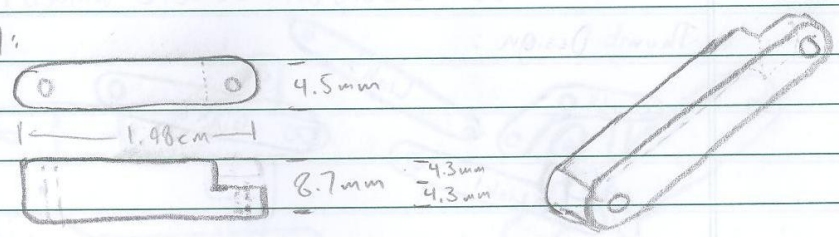


Link 3:

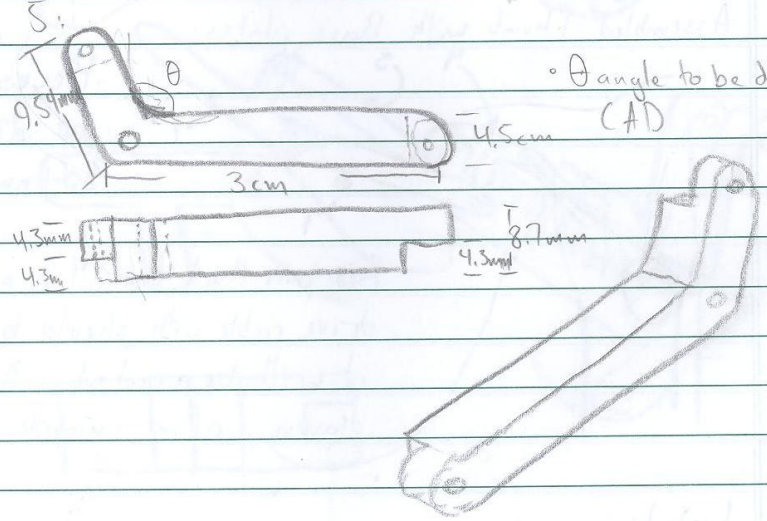




Link 4:

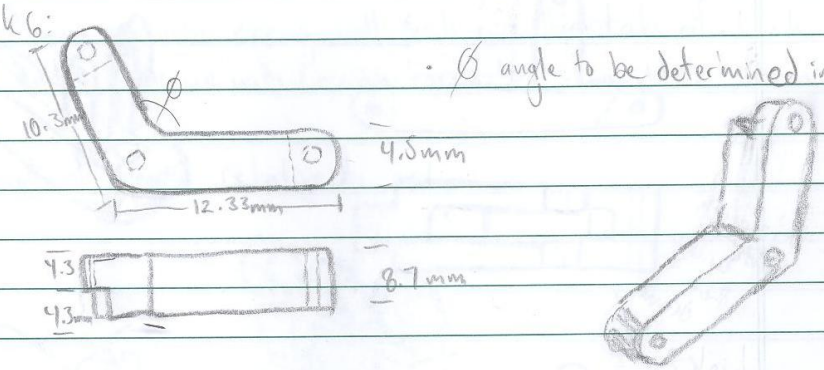


Link 5:



• θ angle to be determined in (A)

Link 6:

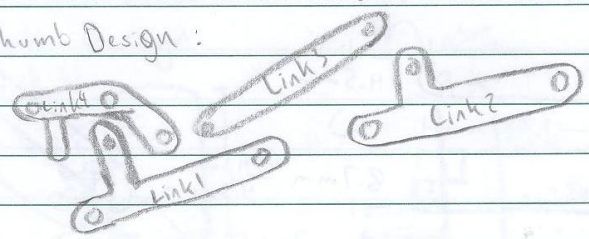


• ϕ angle to be determined in (A)

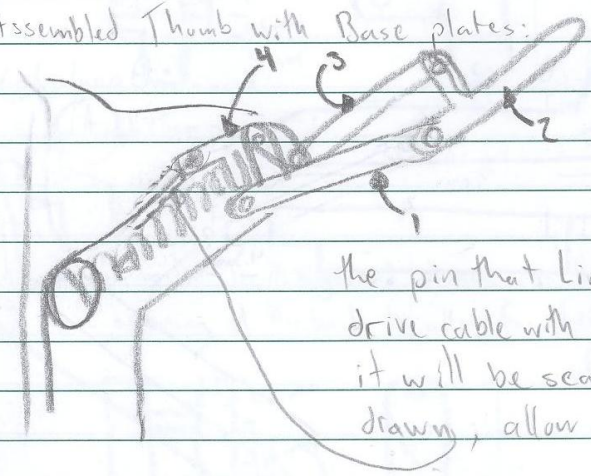
This is to be the finger design pulling on the end of Link 6 will curl the finger. The issue is now how to pull that link with a suitable amount of force in order to be able to grip an object. Also the thumb design needs to be addressed as a thumb will need be included in order to be able to grip objects.

The Rest of the Dimensions will be determined in CAD software

Thumb Design:



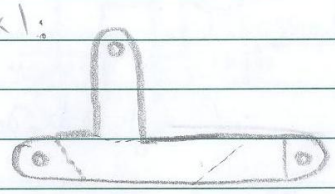
Assembled Thumb with Base plates:

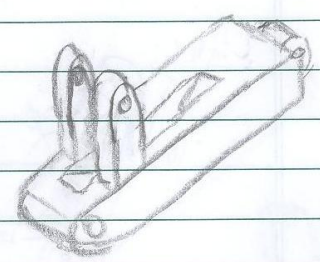


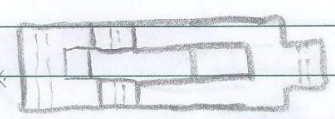
Pieces 1, 2 will be on the Front, 3, 4 and on the back

the pin that Link 4 is attached to the drive cable with should be extra long as it will be seated in the window drawn, allow smooth thumb flexion.

Link 1:

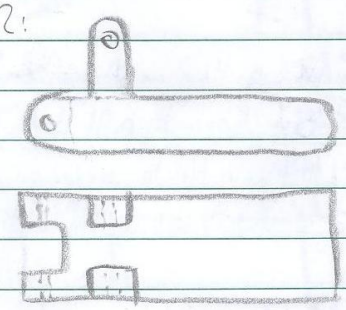


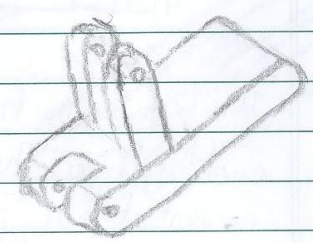




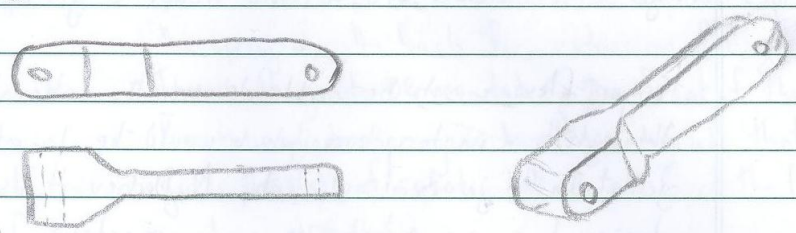
this needs to be wider than drawn

Link 2:

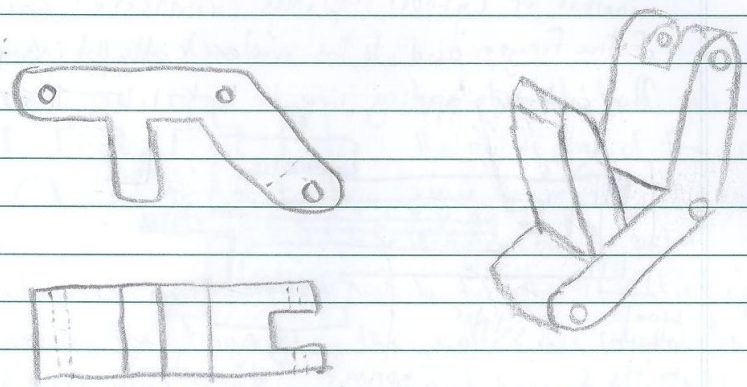




Link 3:

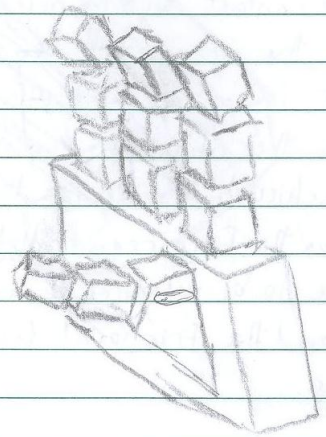


Link 4:



The Thumb return spring will push on the tab of Link 4 when the cable is released with enough force to straighten thumb.

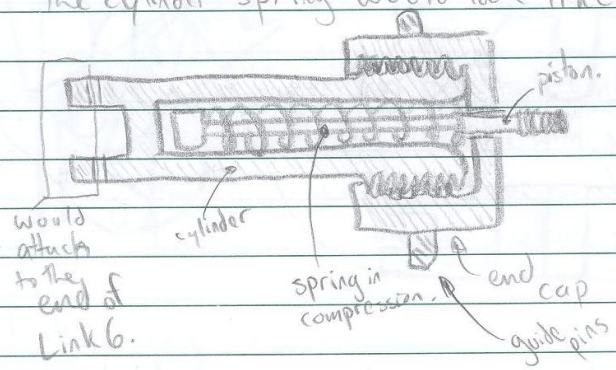
Layout of fingers relative to palm:



A.1.2 – ADAPTIVE GRASP DESIGN

Finger Articulation Method and Adaptive grasp system:

Finger flexion is to be cable driven the cables will be routed through to a motor box which would be located after the wrist joint. In the journal article by N. Dechev it also included a design for an adaptative grasp system. It used a number of cylinder springs connected one side to the Link6 of the finger and to the motor cable being pulled on the other. The cylinder spring would look like this: Cross-section

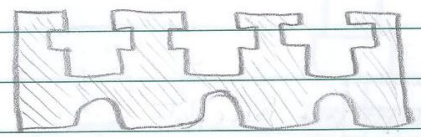


The preload on the spring (The k-value) will need to be high enough to not compressed when it is pulled inwards to curl the fingers. The spring should be compressed once the finger has come into contact with the object it is attempting grip. At which point the springs will begin to compress exert force on the object in grasp while allowing the finger not yet in contact with the object to continue closing until a firm grasp is achieved. The size of the piston and spring will be dependant on the force required to curl the finger freely. This will have to be measured once the finger model is constructed and the frictional forces are measured with a tensometer.

A.1.3 – ORIGINAL PALM DESIGN

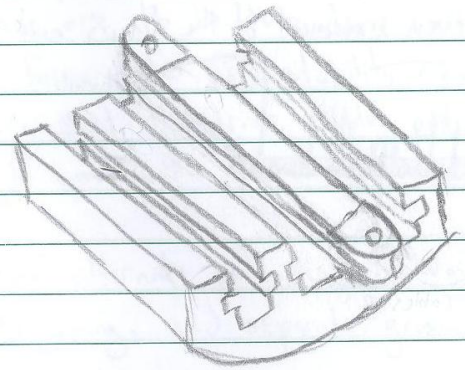
Palm design: - needs to incorporate the three cylinder springs plus the spring on the back for extension of fingers.
- Thumb Design to be mounted on the front of the palm
- Each cylinder spring is to sit in channels that will guide the path of cylinder and Link 6 of the finger as it is drawn in.

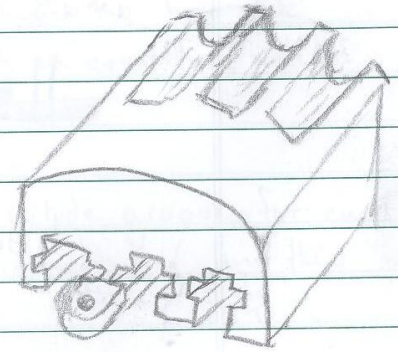
Proposed Cylinder Channels:



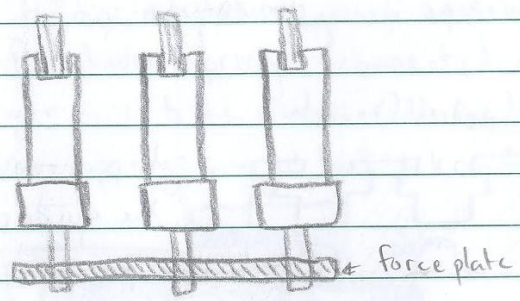
- top channel have side cuts for the guide pins of the cylinder springs to fit into and slide along the length of the palm

- The channels on the bottom will be for the retention spring which will extend the fingers as the cables are relaxed. The springs used here need to be in tension and have a (k value) preload small enough that it doesn't make a significant contribution to the amount of force required to curl the finger, but large enough that it will be able to extend the fingers at a decent rate.

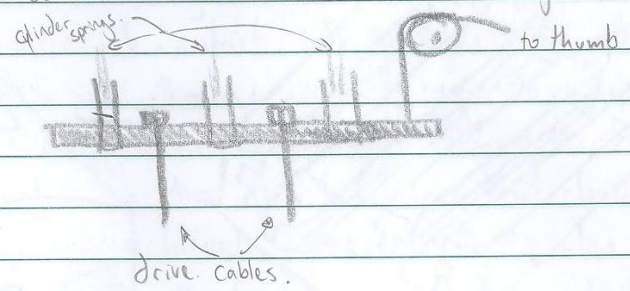




When the Palm is assembled the cylinder springs will be pulled by the drive cable that will be routed past the wrist. The piston need to be pulled in unison. In the N. Dechev design the pistons were attached to a force plate. The Force plate was then attached to the drive shaft which would move the drive shaft forward and back to open and close the hand.

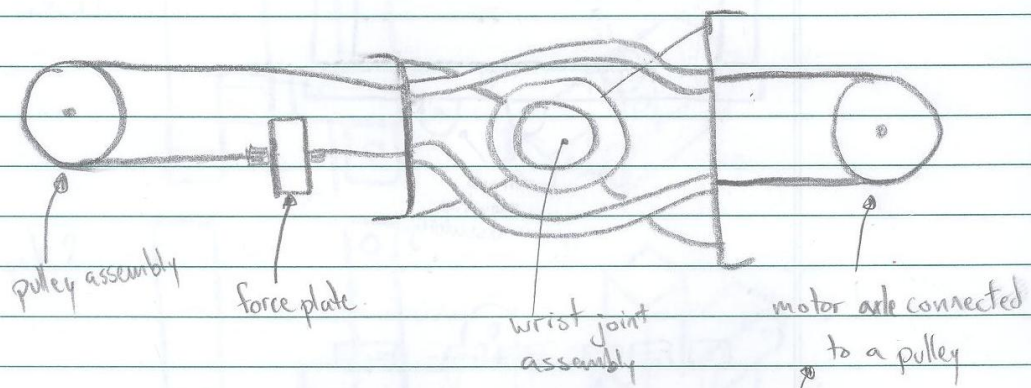


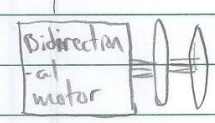
The planned design for our hand however includes a cable driven system. The force plate can still be used but a pair of parallel and equal lines could be attached to the force plate in between the pistons to ensure an even distribution of force pulling on the plates The Thumb can be attached by a cable to this plate but it would have to meet the force plate at a perpindicular angle to ensure the amount the cable is pulled is equivalent to the amount the cylinder springs are pulled so there is even movement of the finger's and thumb.



Alternate finger / palm design:

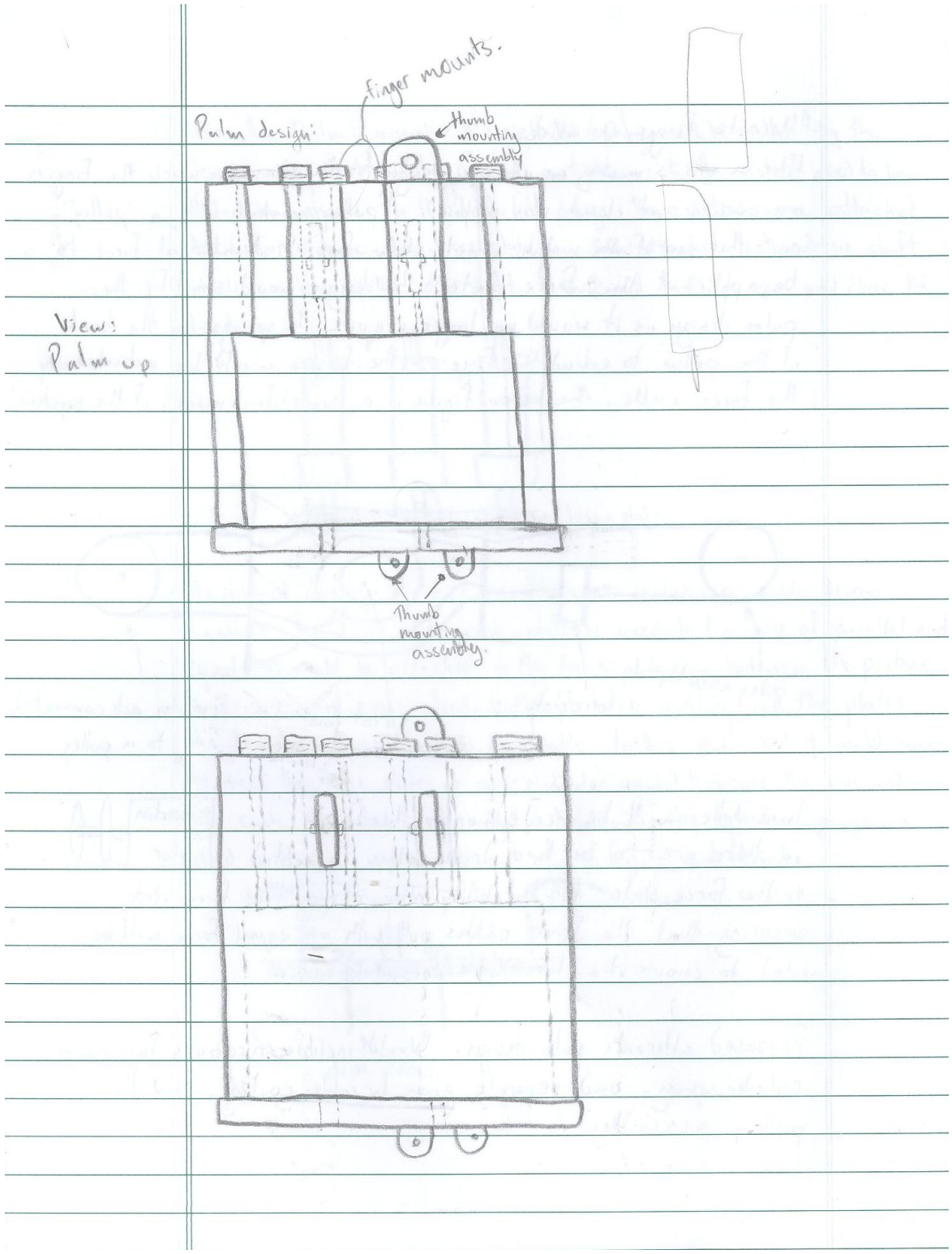
After a group meeting an alternate design for the manner in which the fingers are opened and closed was proposed. A pulley system with a pulley on either end of the system would allow for bi-directional force to be applied at the force plate. The design would simplify the palm design as it would no longer require the springs on the back of the palm to extend the fingers. The fingers would be extended by the force cable, the below figure is a simplified model of the system.





Two pulley's will be needed on either end as there are to be two drive cables connected to the force plate for stability when driving the force plate ensuring that the drive cables pull with an equal force will be vital to ensure the force plate doesn't break.

Proposed alternate palm design: Would include grooves for each cylinder spring, and separate grove for cable routing, and the pulley assembly.


Palm design:
finger mounts.
thumb mounting assembly
Views:
Palm up
Thumb mounting assembly.

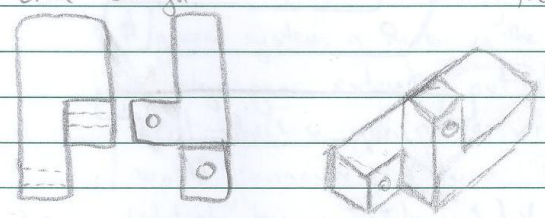
A.1.4 – MODIFIED FINGER DESIGN

· Group Meeting of Nov 10:

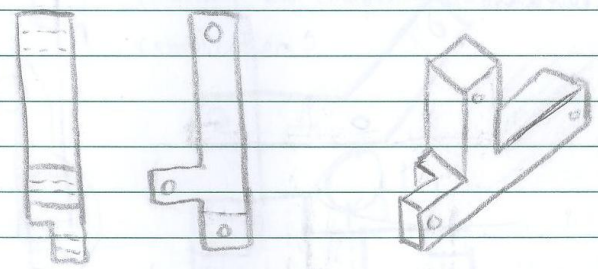
- Discussed w/ professor ideas for design, Sirouspour's response was positive.
- Phil's brother; has volunteered his time to help machine our parts
  - suggested that the parts be modified to allow for easier, faster machining. Suggestions will be reflected in the new drawings
  - No dimensions are to be included as parts will be dimensioned and checked for mobility in (AI) software.

New Finger Link design — Nov 12, 2009

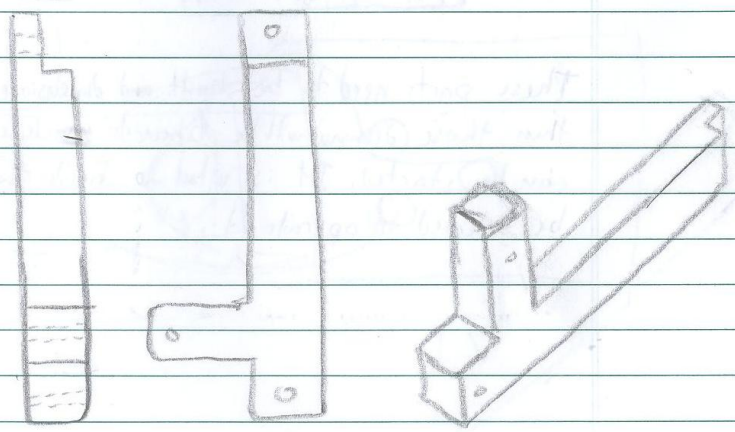
Link 1:



Link 2:

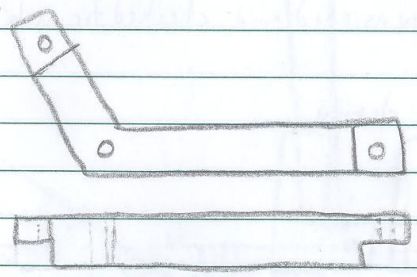


Link 3:

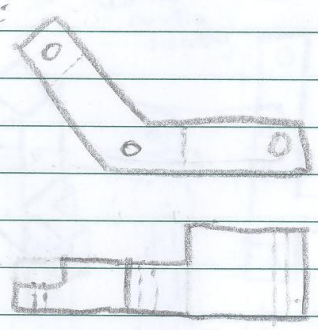


Link 4:

Link 5:

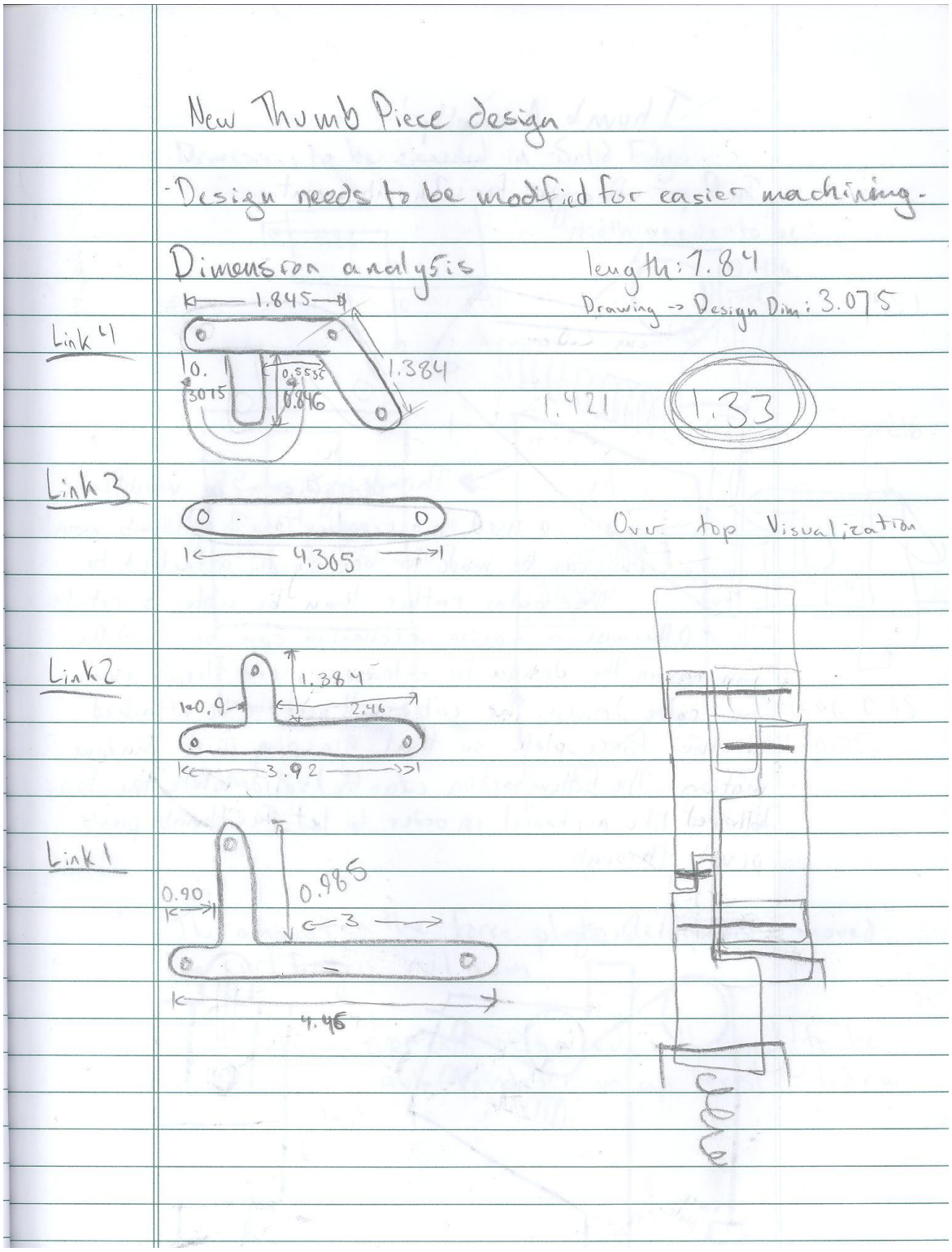


Link 6:



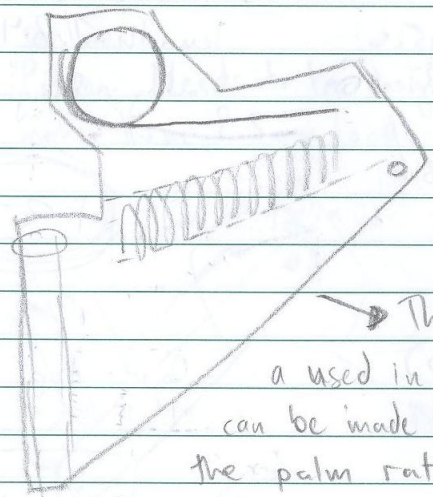
These parts need to be built and dimensioned in AutoCad software then those drawing will be taken to machined so the building process can be started. It is vital to finish the Hand so a motor can be selected to operate it.

A.1.5 – MODIFIED THUMB DESIGN



Thumb Assembly

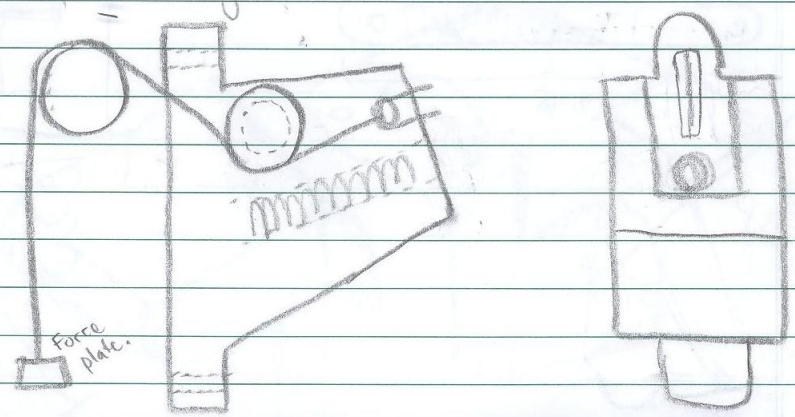
In Paper Design for: Thumb mount.



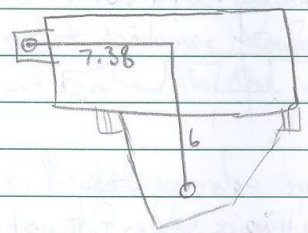
This design can be modified a used in our application. The Thumb mount can be made to be rigidly attached to the palm rather than be able to rotate

Otherwise a spring mechanism can be used the same as in the design for extension, and flexion can be cable driven. The cable will need to be attached to the force plate so that grasping is a tandem motion. The bottom section can be solid while the top hollowed like a channel in order to let the thumb pieces pivot through.

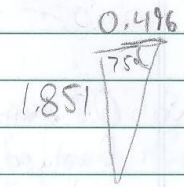
Proposed Design:

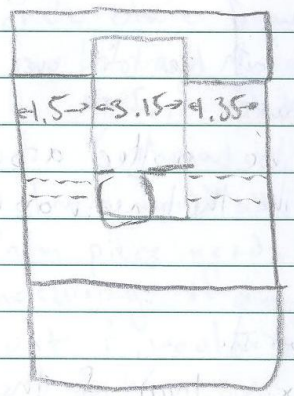


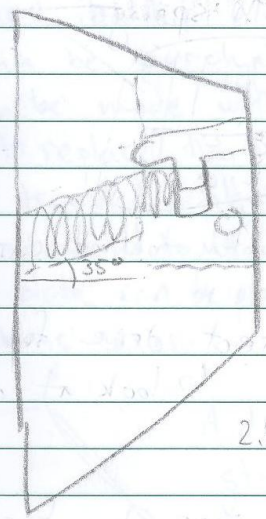
Dimensions to be exacted in Solid Edge

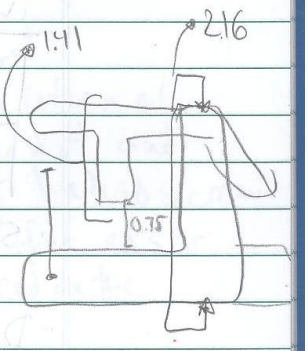


Width needs to be:









1.41 - 0.56 = 0.85

2.16 - 1.41 = 0.75

Width of Cut out

L > 3cm

The amount the force plate needs to be moved to curl fingers ~1.3cm

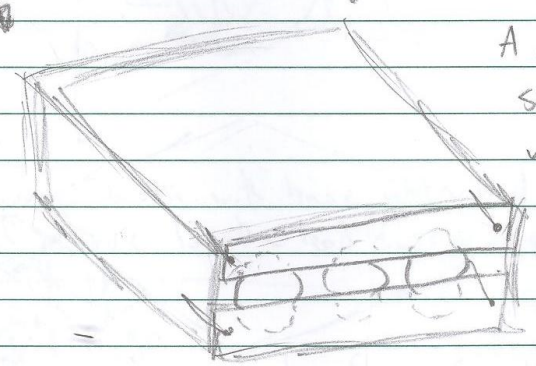
1.6 - 1.15 spring required will need to be able to deform at least ~1.3cm

A.1.6 – MODIFIED PALM DESIGN

March 31st

- At this point were fully taking out the wrist simply designing Hand open and close, if we get that done in the short time we have left then we will attempt to add a rotation with the wrist.

- Possible Redesign of system to pull on force plate. using lead screw and a fly nut to move the force plate forward and back.
  - ↳ Lead screw can be purchased
  - ↳ force plate can be made with internal thread in order to replace the fly nut and would allow for translation along the lead screw.
- Palm piece needs to be redesigned to allow for easier machining. if an end plate can be placed on the front it would make things easier.



A design of two strips spaced apart would be easiest to machine.

it will also need lead screw access from the back? can the motor be mounted directly on to the back of the palm? → a wrist could potentially be built around the motor if needed using a bracket to connect the palm with wrist joint.

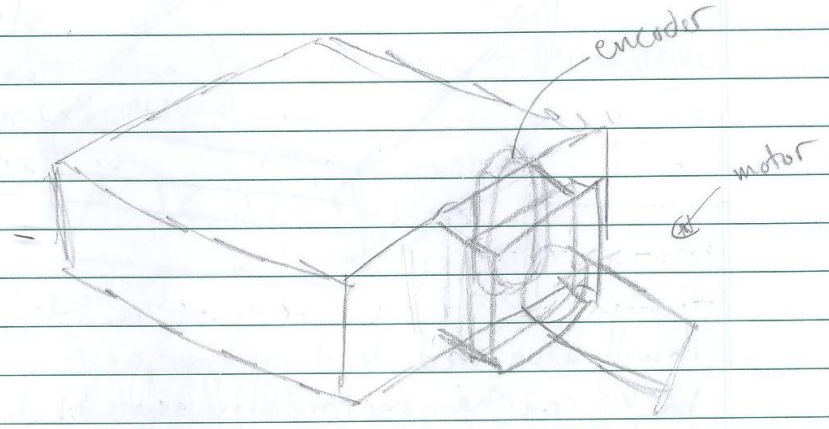
The pistons as they are currently designed are difficult to machine.

↳ Matt suggested the use of a collar for retention instead of an endcap.

↳ the endcap would be like a washer that could be screwed on the washer gauge would have to be small enough that the piston pin does not have any play in it laterally.

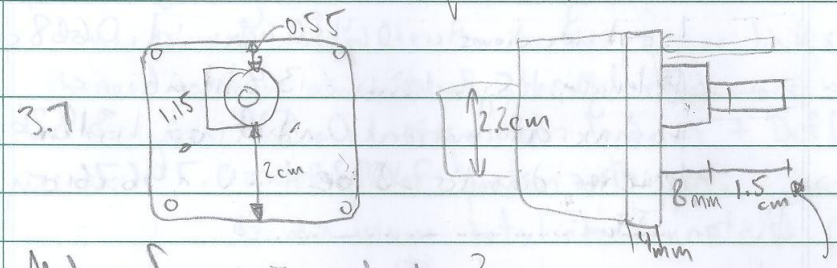
Redesign of Palm with lead screw force plate driving.

↳ Motor can be mounted directly on the base of the palm.



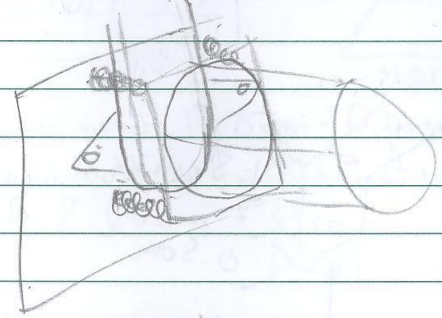
$\frac{42}{100} \rightarrow \frac{21}{50}$

Motor Dimensions: -> Square Face: 3.77 cm



Motor face is set in 2 mm so measurements are from motor face not depth of mounting bosses.

- Encoder needs to be placed on shaft somehow. we need it mounted as well can encoder be mounted onto palm the motor be mounted on top it.



Space between mounting face and palm face: 6 + 10 = 16 mm

Max encoder depth with base attached 9 mm leaving 6mm of spindle for the lead screw to attach to.

Piston Redesign

- choose a spring: Trakar Springs C1067-160-0381S

- Three piece design -> Top cap with extensions to hook up to links of fings
  -> Piston tube
  -> Endplate.

Piston Spring Properties

↳ outside diameter: 0.420 inches : 1.0668 cm

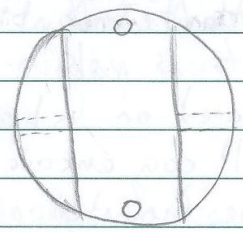
↳ length: 1.5 inches = 3.81 cm

↳ max deformation: 0.519 in = 1.31826 cm

↳ inner diameter: 0.294 = 0.74676 cm

Piston Plan:

top cap:



diameter should be at least twice that of the spring because the piston tube requires anchor points and suitable girth to drill into.

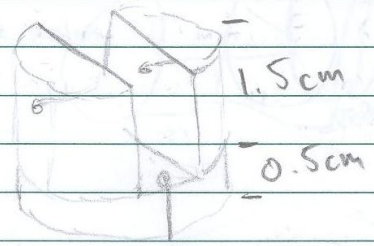
travel required to curl fingers:

↳ 1.4 cm

with compression of springs.

↳ 2.718 cm

↳ 2.7 cm

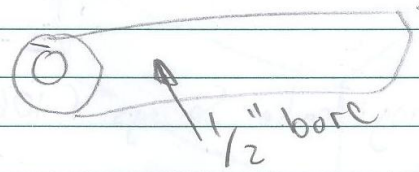


12.7 mm

$2 + 3.9 + 0.7 = 6.2$

1.1

piston tube: basic F'n tube



4cm length

~~1.1cm inner Ø~~

~~3cm outer Ø~~

↳ or 1inch outer Ø

End cap. -> follow outer Ø of tube

-> inner diameter 0.5cm 0.3cm

Piston Pin -> diameter 0.5cm.

-> piston head -> depth: 0.3cm Ø = 1.1

-> length = 5.3cm (full)

Palm Design

↳ needs an endplate to anchor finger links

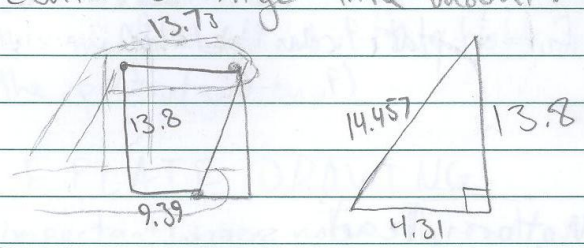
↳ need to know amount of internal clearance → for curl of fingers. → travel required: 1.3cm + Def(0.75)

→ length of piston with pin: cm

↳ minimum total clearance: 11.05cm

↳ max: 12?

↳ Required depth between center of piston pin to center of finger link mount:



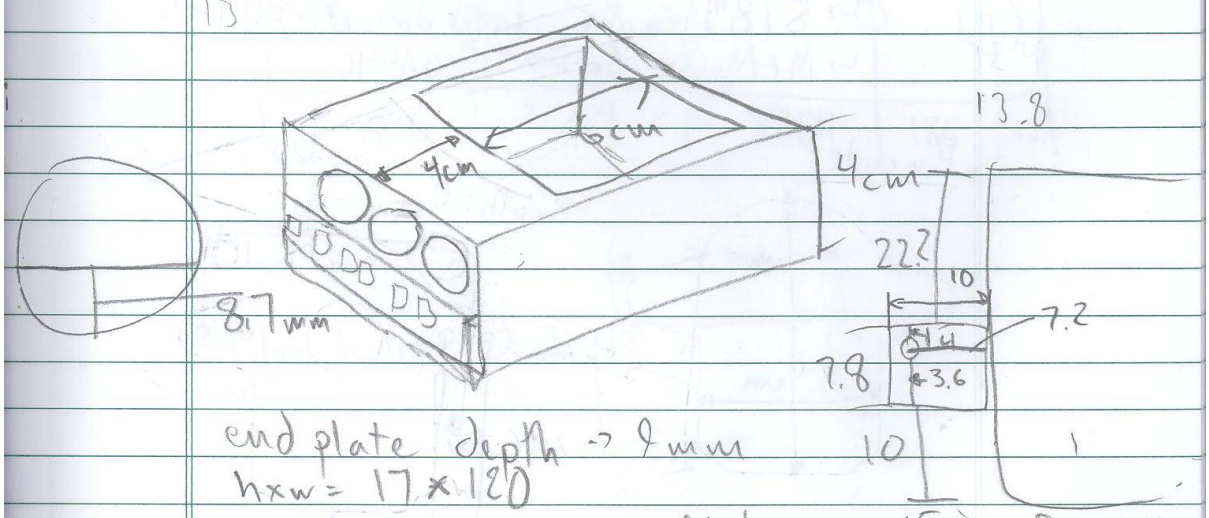
↳ So if we need 13.8mm + 0.5 inch + some xtra on top and bottom for structural integrity

↳ 2.65cm + xtra.

↳

13

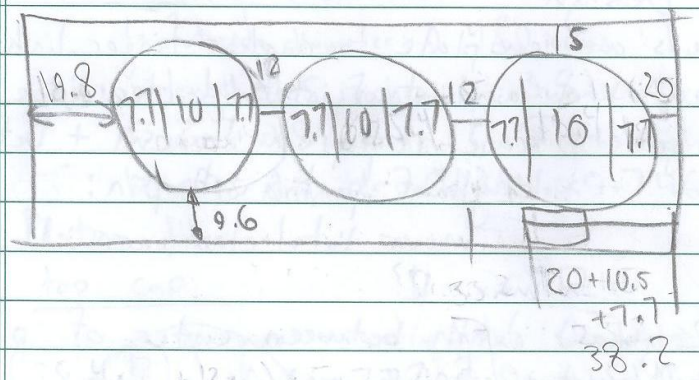
16.2



end plate depth → 8mm

h×w = 17×120

center of hole goes 15mm from bottom

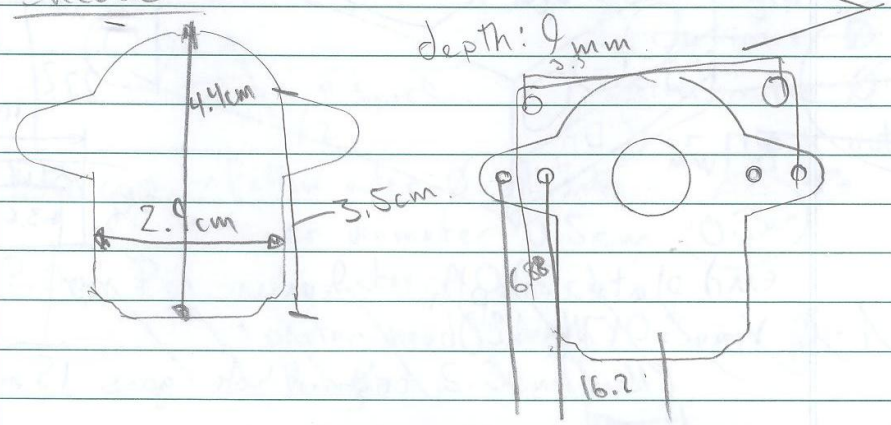


force plate can be <130

Motor lead screw
McMaster-Carr: 93410A908
↳ 3/8"-8

Spacers? need 4, length: 16mm → 0.63
↳ 5/8" length, inner diameter = 0.14"
↳ McMaster Carr → 92510A446

Encoder



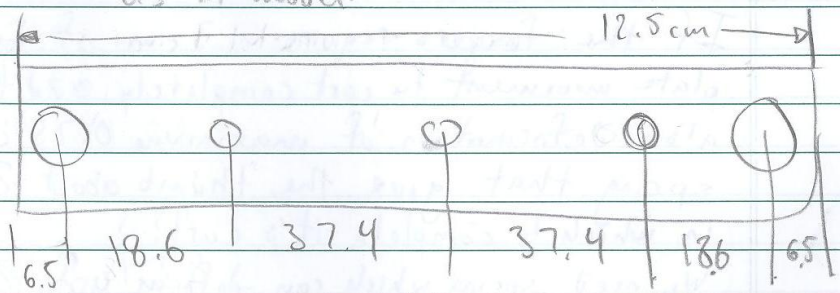
3.58
2.12
5.70

New Piston dim's

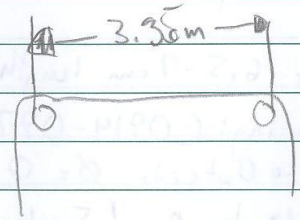
Piston: 91770 A551
↳ 1/4" gauge - 20 thread.
↳ Head → diameter: 0.573"
→ height: 0.150" 8cm + 2.7 + 0.75
↳ 2.35 inches = 5.969 cm

This means Piston inner bore needs to be < 0.573"
↳ Bore length 4cm.
↳ this means 1.67 cm of the bolt is exposed from the piston (good enuf)

- FORCEPLATE DRAWING
↳ important spec note thread on force plate for the lead screws is 3/8-8 Not. 3/8-16 as in model.



9.34 mm



Motor hole → 3.3

A.2 – SOLID EDGE DRAWINGS

All solid edge drawing and assemblies are included on enclosed CD-ROM.

REFERENCES

[1] M.Grob et al, “The Psychological Impact of Servere Hand Injury”, Journal of Hand Surgery. Vol. 33, p 358, 2008, [Online] Available *http://jhs.sagepub.com/cgi/content/abstract/33/3/358* [Accessed: November 5, 2009]

[2] “Hand”, [Online] Available: *http://en.wikipedia.org/wiki/Hand*, [Accessed: March 20, 2010]

[3] Peter J. Kyberd, Colin Light, Paul H. Chappell, et. al, “*The design of anthropomorphic prosthetic hands: A study of the Southampton Hand”* Robotic, vol. 19, pp. 593–600. 2001

[4] Jingzhou Yang, Karim Abdel-Malek and Jason Potratz “*Design and prototyping of an active hand prosthetic device”* Industrial Robot: An International Journal, vol. 32, no.1, pp 71-78, 2005

[5] N. Dechev, W.L. Cleghorn, S. Naumann *“Multiple finger, passive adaptive grasp prosthetic hand”* Mechanism and Machine Theory, vol. 36, pp 1157-1173, 2001