6-2-2015

Micro-motion controller II

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Date: June 2, 2015

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Bergren Antell, Michael McNaul, and Steve Shushnar

ENTITLED

Micro-Motion Controller II

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

BIOENGINEERING

Advisor

Department Chair

Micro-Motion Controller II

By

Bergren Antell
Michael McNaul,
Steve Shushnar

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Bachelor of Science Degree in

Bioengineering in the School of Engineering

Santa Clara University, 2015

Santa Clara, California

MICRO-MOTION CONTROLLER II

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Department of Bioengineering
Santa Clara University
Santa Clara, California
2015

ABSTRACT

The purpose of this project was to improve upon the functionality of a micro-motion controller designed by another senior design group at this university. The original controller design facilitated motion in only two dimensions, and by modifying the platform of the design to accommodate another axis of rotation, we were able to achieve a full range of 3-D motion in our own product. Additionally, we designed a new system in which a motor could be mounted on the base plate of the device which would rotate the upper platform on its own through a simple belt-and-pulley system. And lastly, we designed and added a gripper to the end of the rotating arm that can effectively grab and move objects. Ideally, this project exists as a rudimentary display of the concepts used in various other micro-motion output devices in the biotech industry, such as the DaVinci robotic surgery machine. Practically, we were able to produce a product that was an effective redesign of a system that lacked any sort of 3-D motion.

Contents

List of Figures and Tables

Figures

Tables

1. Introduction

1.1 Background Information

Need for Micro-Motion Control

One of the primary focuses of the bioengineering field as a whole is to create technologies that synergize or mimic the functions of the human body in order to improve the efficiency and effectiveness of the physician and the quality of life for the patient. In the field of robotic surgery, for instance, the DaVinci surgical machine has been used to accomplish over 1.5 million different kinds of surgical procedures, and is continually being developed to accomplish even more. But why do we even need a machine to do surgery for us? Isn't that what our hands are for? Quite simply, the DaVinci surgery machine works better than our own hands do. It is more precise, less shaky, and less invasive than a traditional surgeon could ever hope to be by just using his hands.

One of the mechanisms that makes the Da Vinci surgery machine so effective at assisting surgeons in being both precise and non-invasive is the advanced motion control system that allows the operator to use the arms of the machine as if they were controlling an extension of their own hands. As can be seen in Figure 1.1, the control system functions via the surgeon strapping his thumb and index finger to the device with Velcro straps.

Figure 1.1: Close up of Da Vinci controller interface.

As shown above, this part of the controller can be squeezed in order to interact with a variety of tools that can be attached to the end of the arm. For example, squeezing the controller can activate a scissor tool, a clamp for grabbing suture needles or tissues, or even a syringe attachment.

1.2 Market Status at Present – Major Manufacturers and Market Opportunities

Currently, the biggest player in the robotic surgery market is Intuitive Surgical, the maker of the Da Vinci surgery machine and all of its extension tools (~68% market share). As more advanced surgery techniques are developed for more delicate procedures, the human hand will become more and more limited in what it can accomplish, and the need for more advanced surgery techniques will grow, and along with it, market opportunities for new systems. As can be seen in Table 1.1 below, Intuitive Surgical's financial growth over the past 5 years has been simply astonishing.

Table 1.1: The sources below represent the current adaptation of the micro-motion controller.

Intuitive Surgical Inc. (US robotic surgery equipment sales) – financial performance

Year	Revenue ($ million)	(% change)	Net Income ($ million)	(% change)
2009	443.7	36.0	98.1	28.9
2010	602.2	35.7	162.7	65.9
2011	764.0	26.9	215.3	32.3
2012	984.3	28.8	296.6	37.8
2013	1,430.2	45.3	423.7	42.9
2014*	2,002.3	40.0	498.2	17.6

*Estimates

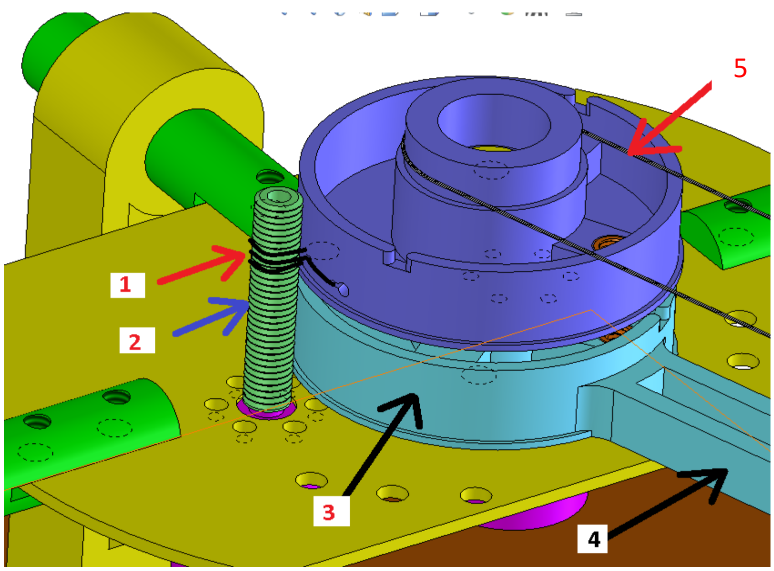
SOURCE: ANNUAL REPORT AND IBISWORLD

The likely reason for the roughly $4 million boom in 2013 was Intuitive's response to hospitals' and medical practices' demand for low-cost systems with limited features that could be used to provide a high volume of similar surgical procedures. As they continue to tailor their products to meet more specific demands, it is likely that their market share will increase even more.

As this is such a lucrative market with such a high potential for helping to improve the medical treatment of patients, our goal with this project was to gain an understanding of the basic mechanical principles of micro-motion control as well as create our own rudimentary system from another group's design.

1.3 Literature Review

The previous SCU micro motion controller project provided the foundation for our own design. We redesigned the previous team's rotating arm assembly to fit a different need. The original design was a revolving drum mechanism that rotated around a fixed z-axis to provide a full range of motion in



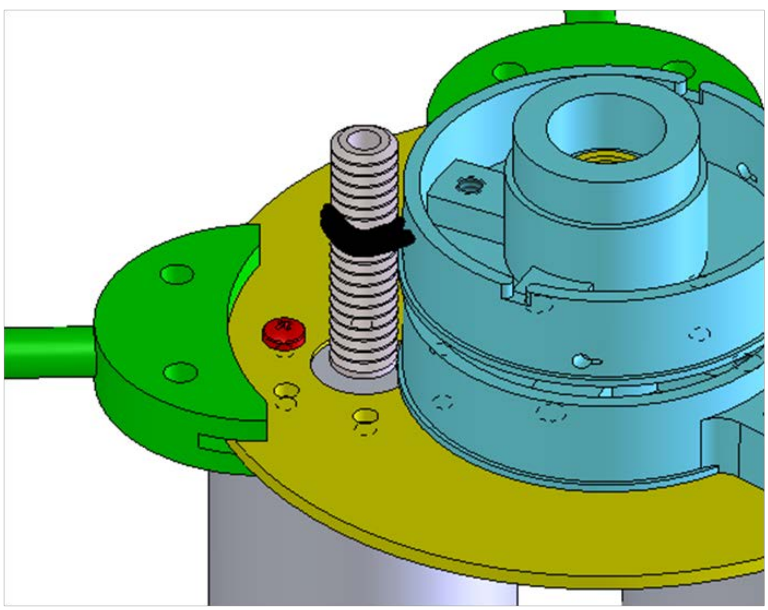
1: Rubber O-ring damping
2: Cap stand from motor
3: Revolving base of proximal arm
4: Proximal Arm
5: Tungsten Wire

Figure 1.2: Revolving drum mechanism.

The purpose of the previous project was to find a micro-control technology for reducing tremors from the surgeon's hands during microsurgery. Microsurgery requires precise procedures and delicate motor control, so the steadiness of the surgeon's hand can have a direct effect on how invasive the operation is. One small micro tremor or slip can cause tremendous damage to the patient if it occurs. One of many reasons that the Da Vinci surgical system has been so successful is that it significantly dampens the motion of the surgeon's hand to prevent him from causing unnecessary harm to the patient should they make the slightest error in moving their hands and fingers.

The previous Micro Motion Control design group achieved damped motion by placing rubber O-rings around the revolving shafts that are connected to the drum via tungsten wires. This can be seen in Figure 1.3 on the next page.

Figure 1.3: The previous group's O-ring damping mechanism.



In repurposing the original design, we decided that we would not incorporate this feature into our own product because we aren't particularly concerned with steadiness in our device. The stepper motors we used proved to be capable of moving steadily enough to accomplish the desired task. Additionally, we were looking to create an output mechanism that would amplify the motions that a disabled person would potentially put into the controller, not dampen them.

In the previous project, there was no facilitation of 3-D motion whatsoever. An important distinction between our project and the previous group's work is that the plate from the previous design project was not free to revolve, as illustrated in Figure 1.4 on the next page:

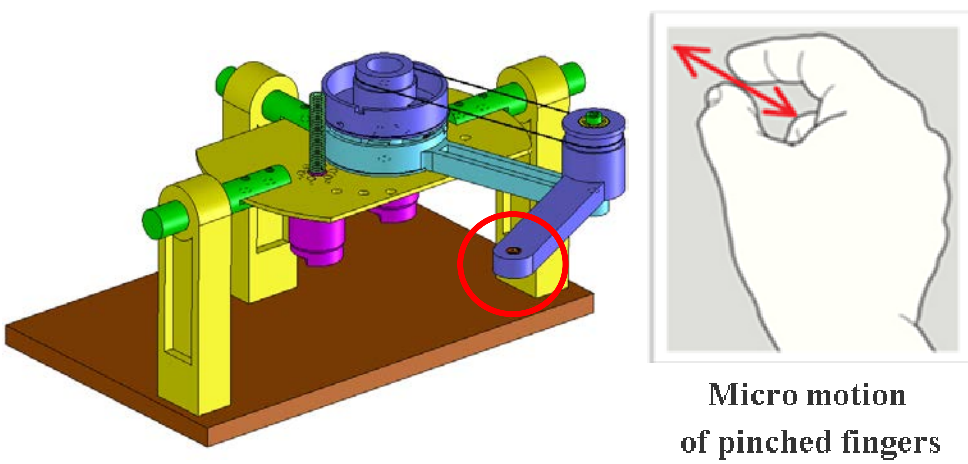


Figure 1.4: The fixed range of motion of the previous project

The fixed plate was sufficient for the original design because the previous project was only intended to explore options in damped motion for microcontrollers. It was specifically meant to imitate the micro-movement of the human hand as its movements are damped in a linear motion. It was never intended to create a system capable of picking up objects, which was a primary goal of ours. We therefore removed one of the posts from their design to allow our plate to revolve, which facilitated the "pseudo 3-D" motion used to move the gripper.

1.4 Starting Project Goals and Objectives

- CAD – To create a workable model that achieves the design requirements
- Test – To pass our CAD design for physical stress and durability.
- 3D model – To prototype the mechanical functionality of the design
- Redesign – To make any necessary improvements to the foundation of our rotational controller add-on.

1.5 Customer Needs

The end goal of this project is to provide the user with the ability to fully move and rotate objects with small wrist movements. The idea originated from the Intuitive Surgical, Inc. DaVinci robotic surgery platform used to perform robotic operations. The goal of the DaVinci is to expand the capabilities of arthroscopic surgery, or minimally invasive surgery done through the use of an arthroscope, that allows for a lower risk of complication and increased healing time by definition. However, in distancing the surgeon from the patient's internals, the decreased risk of infection can be mitigated by decreased accessibility. Designing a micro-motion controller allows for smaller and more-precise movements to better emulate handheld surgical scalpels.

Applying the micro-motion controller design to an isolated system differentiated our system from the other team. Rather than interface this design with the larger DaVinci robot, our team created an isolated system that provides those without upper body movement the ability to manipulate objects. Simply put, our system allows for the paralyzed to play chess without bionic limbs. Our research on medical device industry led us to the following conclusions:

- The paralyzed will be frugal in purchasing a device that has such a specific purpose.

- Having increased ability at a lower price than bionics is a luxury, which will be entirely funded by the patient.

Those who suffer from tetraplegia require greater flexibility in their bionic devices. The social response to physical actions with another person is much more powerful to the patient than the interaction with virtual systems.

1.6 System Capabilities

The aim of the system is to improve the capability of the micro-motion controller by allowing it to function in the z-axis. Although this will not qualify as a freely moving z-axis rotation, the angular rotation in the z direction allows for increased torque and much more stable movement in turn. Beyond the motor-pulley system, a 'gripper' attachment is affixed to the baseplate's rotational arm. The gripper is actuated by a solenoid and a small pneumatic compressor.

1.7 Performance Requirements

1. Rotation of the motor-pulley system must occur to move the arm from level to 45° in 0.5-1.5 seconds.
2. Micro-motion controller must act in the Z-direction to lift and drop chess pieces. Adding a Z-axis allows greater device functionality.

Angular Z-axis movement achieves functionality with more stability of the mechanical arm. Rotating the x-y axis original micro motion controller angularly gives necessary functionality in such a confined space with great precision.

1.8 Functional Analysis

At the most basic level, our micro-motion device contains motor-driven pulleys and a pneumatic gripper to achieve basic robotic function. The first pulley system is driven by a large motor in the rear attached to a belt that allows the upper platform to rotate in the angular Z-direction. The next pulley system is driven by two stepper motors underneath the upper platform. These motors are connected to tungsten wires that control moving the plastic arms in the X and Y directions. Finally the pneumatic gripper is an air-driven gripper that opens and closes to pick up chess pieces. All of these components are controlled by an electronic motor control board.

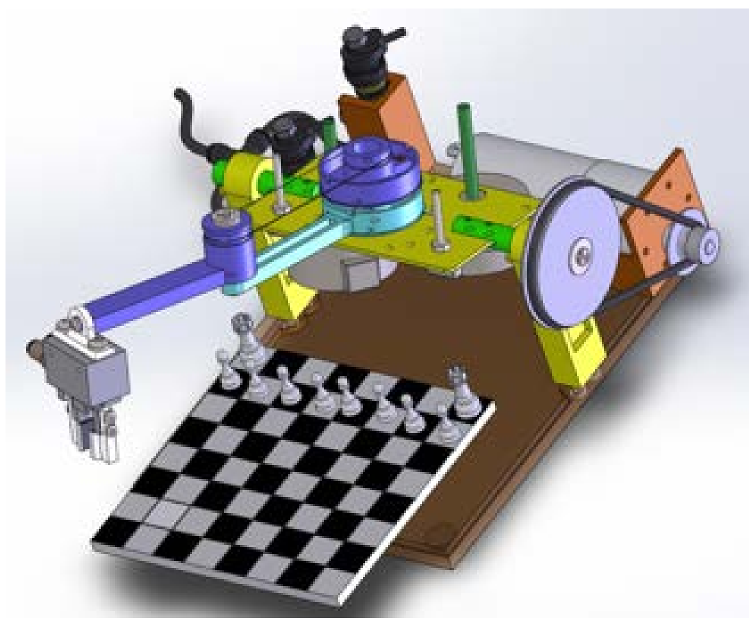


Figure (1.5) Solidworks Isometric View of the Micro Motion II device (above).

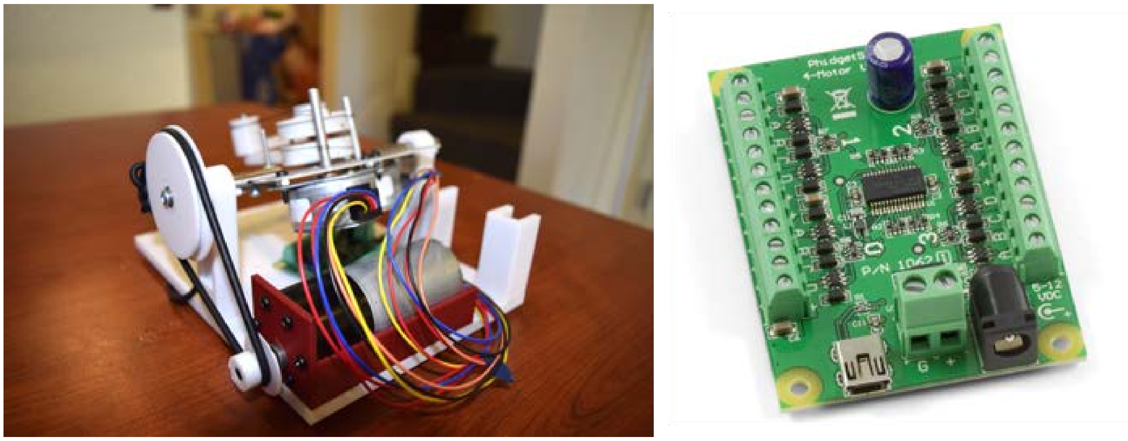


Figure (1.6) Rear view of Micro Motion II device (left) and Phidgets® Motor Control Board (right).

1.9 Benchmarking

In terms of benchmarking, our primary goal was to deliver a prototype that provided motion to the quadriplegic user. Our model reflects the need for the robotic gripper to be able to grasp and manipulate a chess piece in 3 dimensions to move the pieces. Due to the small market size for bionics, there are limited models to compare this device to. However, there is a basic capability to manipulate objects that enables basic usability for tetraplegics.

The most basic biodevice is the U-Cuff that tetraplegics use to manipulate objects with a simple tenodesis pinch. In our interview with Catherine Curtin, M.D., we were able to understand the abilities this simple wrist support device contains. The device itself has the simple capability to aid grip and the bending of the wrist for the tenodesis pinch. Our device allows for basic pinch functionality through the pneumatic gripper.

More advanced devices such as the Ottobock® Michelangelo Prosthetic Hand allows for physical gripping as an extension of nervous system. This below elbow prosthesis allows for electrode connection to skeletal muscles that activates a 'main drive.' This main drive controls an active thumb, index finger, and middle finger. Unfortunately, this devices is only suited to those who are upper limb amputees with fully functioning nervous system. However, this device, which enables user-controlled grip and hold strength, makes a fantastic end goal for our design.

1.10 Project Scope

As noted above, the scope of this project was to design a rudimentary pick-and-place machine meant to mimic delicate motions of the human hand to accomplish delicate and precise tasks, such as playing chess. We acknowledge that our project is presently far from practical for industry standards, but we hope that this project will contribute to the development of better micro motion systems. We modified an existing design of a damped input device operating in a single plane by adding additional components, improving the range of motion, and turning an input device into an output device.

1.11 Budget

Unlike the original micro-motion controller design, this project was funded entirely by the Santa Clara University Undergraduate School of Engineering. In February, 2015, the team was appropriated a $1,500 grant to build a physical model of the micro-motion controller. Budget funding can be found in Appendix B.1.

Funding allowed for the prototype molding and 3D printing of the components for the micro-motion controller. In addition, mechanical assemblies were purchased with the Undergraduate School of Engineering grant that allow for a functional motorized system. The team also worked in the Santa Clara University ‘Maker Lab’ to construct particular pieces. Instructional training and access to the 3D printing and tooling was similarly provided.

Considering the limited timeline mentioned earlier, the budget did not constrain our project. In addition, the concepts were created with the budget in mind. A CAD and motion analysis approach was undertaken in Solidworks®, with a physical assembly built as a proof of concept. In addition, materials were chosen based on the budget. Due to the small size of the device, printed ABS plastic and machined aluminum parts provided adequate tensile strength and frugal cost.

1.12 Timeline

The team undertook the project week 6 of the Winter Quarter and worked quickly to establish a baseline for the project. The immediate goal by the end of the Winter quarter was to construct a CAD prototype and outline the necessary tests for the modified micro-motion controller. All CAD designs and mechanical analyses were completed by the end of the Winter Quarter (mid-March, 2015).

The second aspect of the micro-motional controller with a rotational add-on was the physical construction and virtual testing of the design during the first 4 weeks of the undergraduate Spring Quarter, 2015. Due to the limited time to build the prototype, any breakage in physical stress-strain tests could not be rebuilt in a timely manner. Outside of this limitation, the timeline worked well for the design and testing of the micro-motion controller model.

The team followed the timeline closely during the Winter Quarter and purchased all parts by the one-week break. This break allowed for a lead-time on the parts supplied from distributors to build the model. It also evenly divided the two time segments of design and testing.

1.13 Risks and Mitigations

One of the major risks for the project was for the movement to be inhibited in the physical prototype. In re-designing the micro-motional controller in such a short period of time, limited effort could be allocated to Solidworks® Motion Analysis before ordering the physical components. Especially with the gripper mechanism, gravitational forces had to be accounted for in allowing the bearings to sit the gripper vertically. Fortunately in our initial design assembly, this was not an issue.

Table 1.2: Risk Matrix

Probability (P) = [0,1]; Severity (S) = [1,10]; Impact (I) I=P*S

Risks	Consequences	P	S	I	Mitigation Strategy
Limited Motion Analysis Before PO	Non-functional prototype; Run out of funds	.1	7	.7	Discuss forces with Independent Advisor
3D Printed Parts Not to Specified Dimensions	Dysfunctional prototype	.3	4	1.2	Check dimensions of each part; Mill down components
ABS Part Breaks	Dysfunctional prototype	.2	.4	.8	Order additional components
Limited Computer Hardware for CAD	Lagged Motional Analysis	.8	1	.8	Speak with System Admin
CAD file loss or file corruption	Loss of time; restart design	.05	10	.5	Backup to Dropbox®

1.14 Team Management:

When the project began, all group members were assigned specific tasks to be completed since we did not have enough time to work together on all tasks. For a detailed chart of assigned duties to each group member prior week 5 of Spring Quarter, see Appendix B.2.

Starting week 5 of Spring Quarter, duties were split as follows:

- McNaul: Finalize design details, assemble product, seek outside help for the GUI.
- Shushnar & Antell: Prepare presentation for Senior Design Conference, write thesis document, and take finished product to VA hospital for feedback.

2. Design Components

2.1 Motor-Pulley System

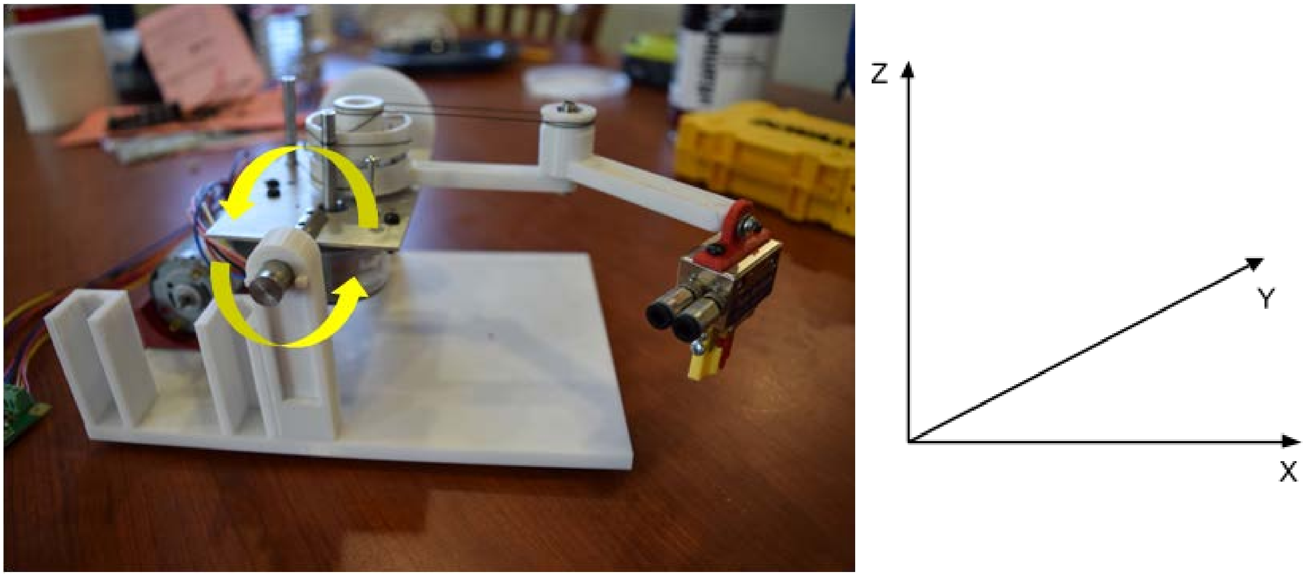


Figure 2.1: The revolving "pseudo-3D" motion

The motor-pulley system was the concept that we utilized in order to facilitate what we will refer to as "pseudo 3-D" motion of the device. This is illustrated in the figures below.

As can be seen, our device is actually incapable of true 3-D movement. Although it has full range of motion in the x-y plane in front of the base plate, it cannot actually move straight up and down along the z-axis as labeled on the right. This is because the drum is locked into position on the base plate. The way that we obtained an extra degree of freedom was by rotating the base plate while simultaneously moving the arms of the mechanism in and out. The base plate is connected to a rotating pulley system which is powered by the motor, as can be seen behind the rotating drum in the picture above. As the motor rotates, the revolving motion is transferred to the pins that hold the base plate by a rubber cable. The pins are held in place by force-fitting them into the holes in the posts of the device. We originally intended to use a gear assembly, but we abandoned this design plan in the sake of getting the project done on time. We kept the simple cable-pulley since it was a quick simple solution to getting the plate to rotate with the limited time that we had.

2.2 Pneumatic Gripper Control

For this project we decided to use a type RH 901k pneumatic gripper from Schunk with our own added 3-D printed gripping prongs.

Figure 2.2: 3-D gripper "fingers "and rotational top joint created in Solidworks™

This gripper places about 2.759 N/m^2 of force on the chess pieces, which is a fitting for simple pick-and-place actions. We needed to 3D print custom prongs to grip the chess pieces. Unfortunately, this product as a whole is not yet capable of being used with an off-the-shelf chess set. For the intents of this project we had to calculate the total range of motion in the x-y plane by the device and cut and laser our own custom chess board to fit the gripper. The gripping prongs are therefore limited to this specific chess setup, and aren't workable for any other chess set.

2.3 Previous Design to New Design Comparison

The original Micro Motion I design (Figure 2.3) served the simple purpose to take feedback from a pressure input at the end of the arm. The motors depicted underneath the top plate act to sense the pressure input transferred through the moving arm. In the Micro Motion II design, the back post is removed so that the arm mechanism can move in the vertical direction with the help of a motor. Additionally, the sensory motors are “flipped” so that they may move the arms to a desired location. Additionally, a gripper was added to the end of the arm so that chess pieces or objects can be picked up.

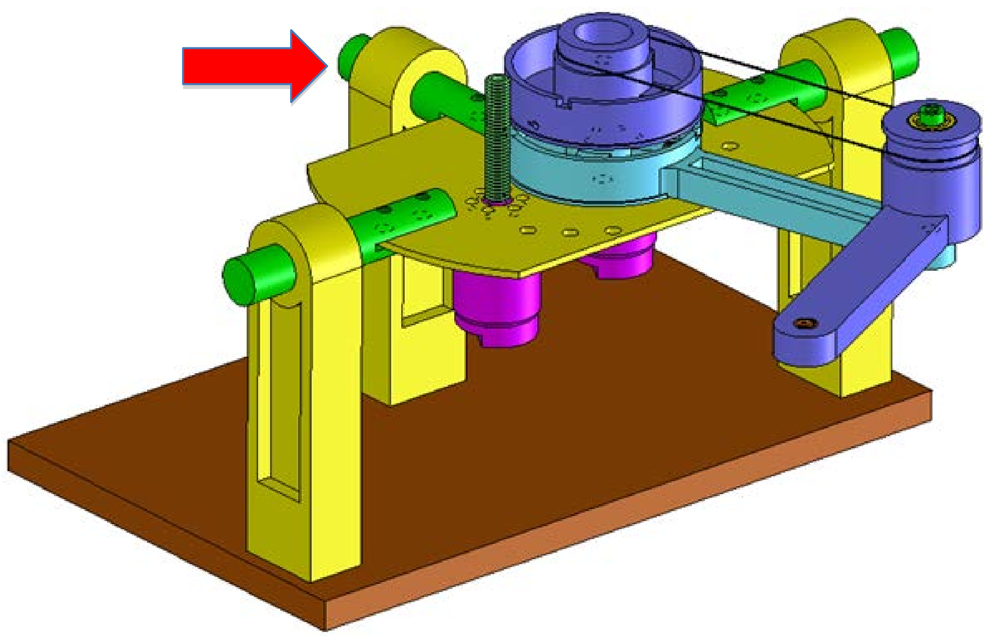


Figure 2.3. Micro Motion I

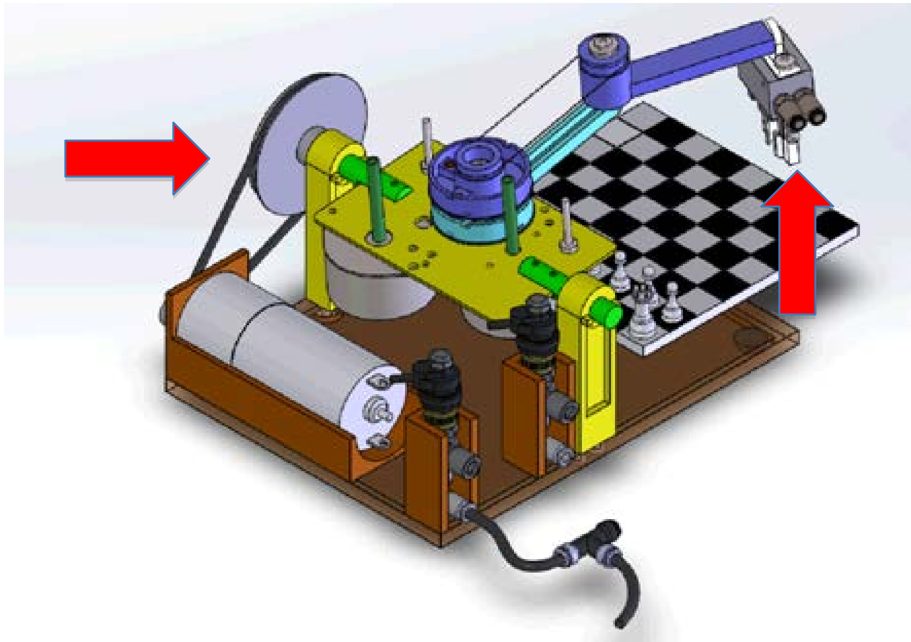


Figure 2.4 Micro Motion II

2.4 Design Using Solidworks™

The computer aided design was done through Solidworks to build our specific parts and model the system. Our design began with the Micro Motion I input device design. The process completed as followed: deconstruct the original system; re-construct with additional components; and test the motion and stresses.

2.5 Deconstruction

The main purpose of deconstructing the original Micro Motion I CAD file was to allow the gripper platform to rotate in the third dimension. This method involved removing the backmost post of the Micro Motion I to successfully allow for rotation with the other two. Additionally, mates between parts were re-configured to accommodate movements not present in the Micro Motion I device.

2.6 Manufactured Parts

Manufacturing of the components was done through custom machining and 3-D printing. In reconstructing the CAD model, we had to begin with expanding the baseplate to fit the large motor pulley system in the rear. Many of the fixtures were created to fit the purchased stock pneumatic gripper and stepper motors. For instance, the 3-D printed gripper ends created in Solidworks® were better able to grip the chess pieces than the stock gripper ends (See Figure 2.5).

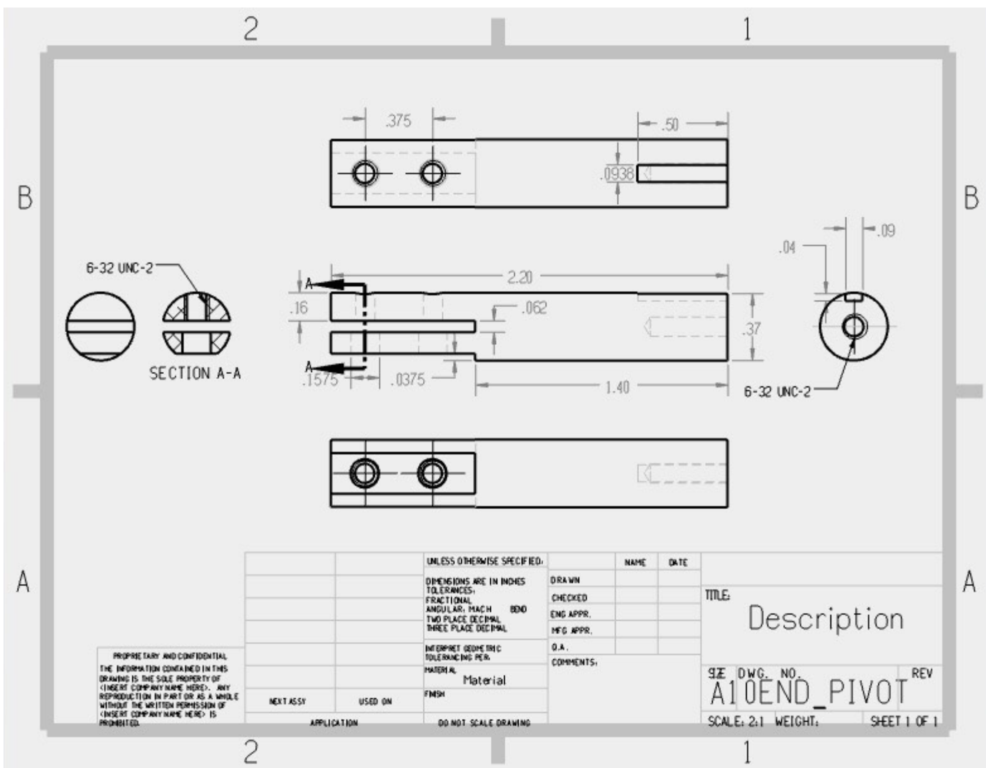


Figure 2.5: End Pivot shaft built around XY baseplate and pulley system.

Our design for the pivot shafts were custom machined from stock shaft specifications to hold the Z-axis pulley wheel.

2.7 Stress Analysis

Stress analysis gives us the ability to look at both the strength and power transfer within our system, as well as the manufacturability. Making a prototype involves figuring out what the best materials are for the system. The stress analysis in Solidworks® allows for us to have more than a simple educated guess as to what loads the system can hold. For this first prototype, computer modeling must use materials similar to those used in fabrication. For the intents and purposes of this project, we used PVC since it closely resembles the physical properties of ABS plastic. This is a necessary step in accurately estimating the cost of manufacturing, and what will happen physically if we expand the model size.

There are two key areas for motion analysis: the motor pulley systems and the pneumatic gripper. We did not have access to the force gauges necessary to measure the tensile strength of the tungsten wire and Z-axis belt and subsequently were not able to calculate this power transfer due to friction. We were, however, able to calculate the material stress of the pneumatic gripper upon actuating at full force.

Figure 2.6 below allows us to understand the forces affecting the gripper ends as the gripper is actuated. In our current design, the gripper is programmed to actuate on and off. For future designs, we wanted to find out how much load the gripper hands could handle. The shaft calls for specific tolerances that allow for a close fit between the XY motor plate, pulley wheel, and support stands. Figure 2.6 below shows a stress gradient for fracture stress between the different material components.

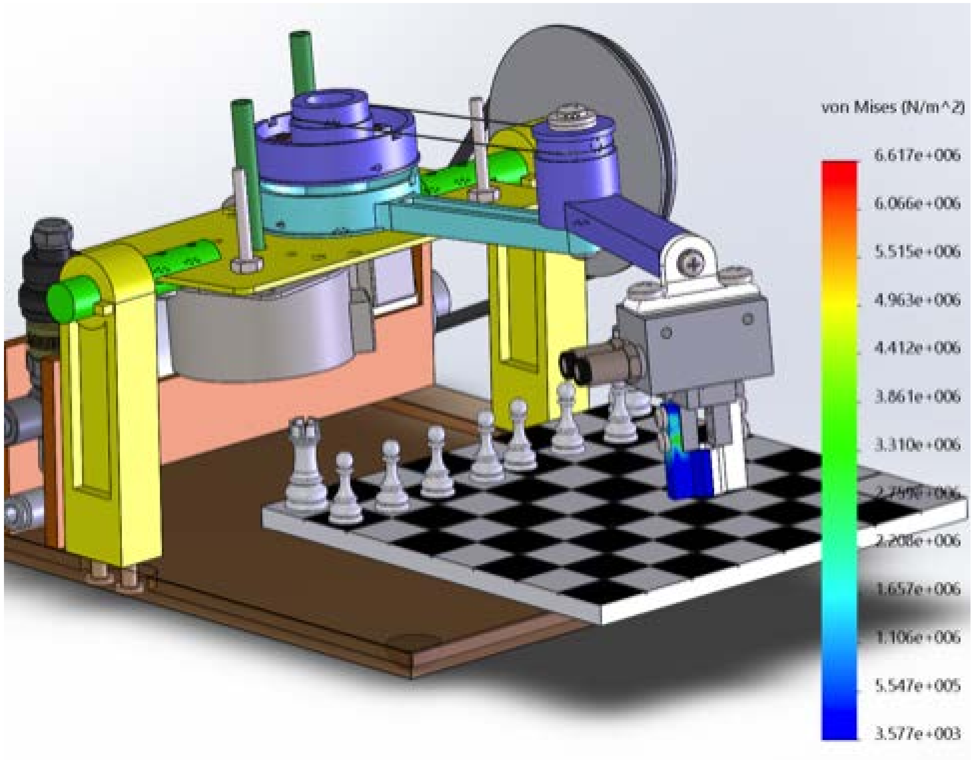


Fig 2.6: Stress Analysis done in Solidworks®

2.8 Gripper Research

In understanding the relevance of our gripper to the human hand, we first had to find what scale force the human 'pinch' had. Our research found that in order for the human index finger and thumb to grip an object a constant minimum of .45 pounds was necessary. Moreover, according to a study at McGill University in Canada, 2-2.25 lbs was the maximum pressure exerted by the human 'pinch' (Ramsay et. al 1994). By implementing a virtual linear actuator (linear-driven motor), we were able to find that gripper contact force was able to reach approximately 18 lbs of force. This puts our device with high weight polyethylene grippers (UHMWPE) well within range for use. Moreover, the contact force graph (Figure 2.7, left) denotes the initial 'jump' to approximately 2 lbs of force. This result represents a similar [Similar to what, though? Note entirely clear, but I may have missed something.] minimum grip force by the pneumatic gripper before it begins to deform the gripper ‘hands’ connected to the motor.

This allows for promising results in the future as a gripper with multiple pressure modes.

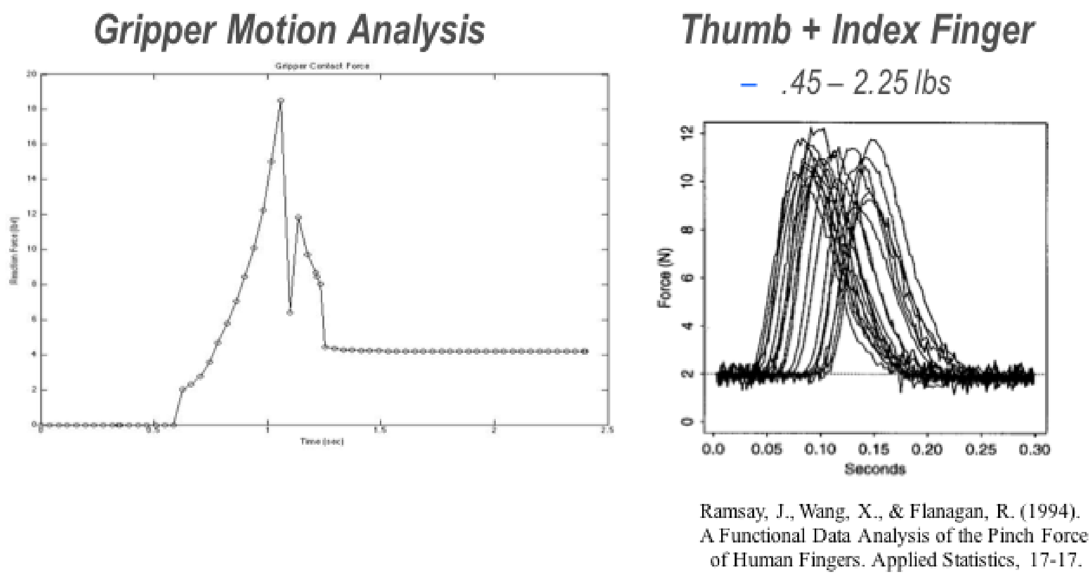


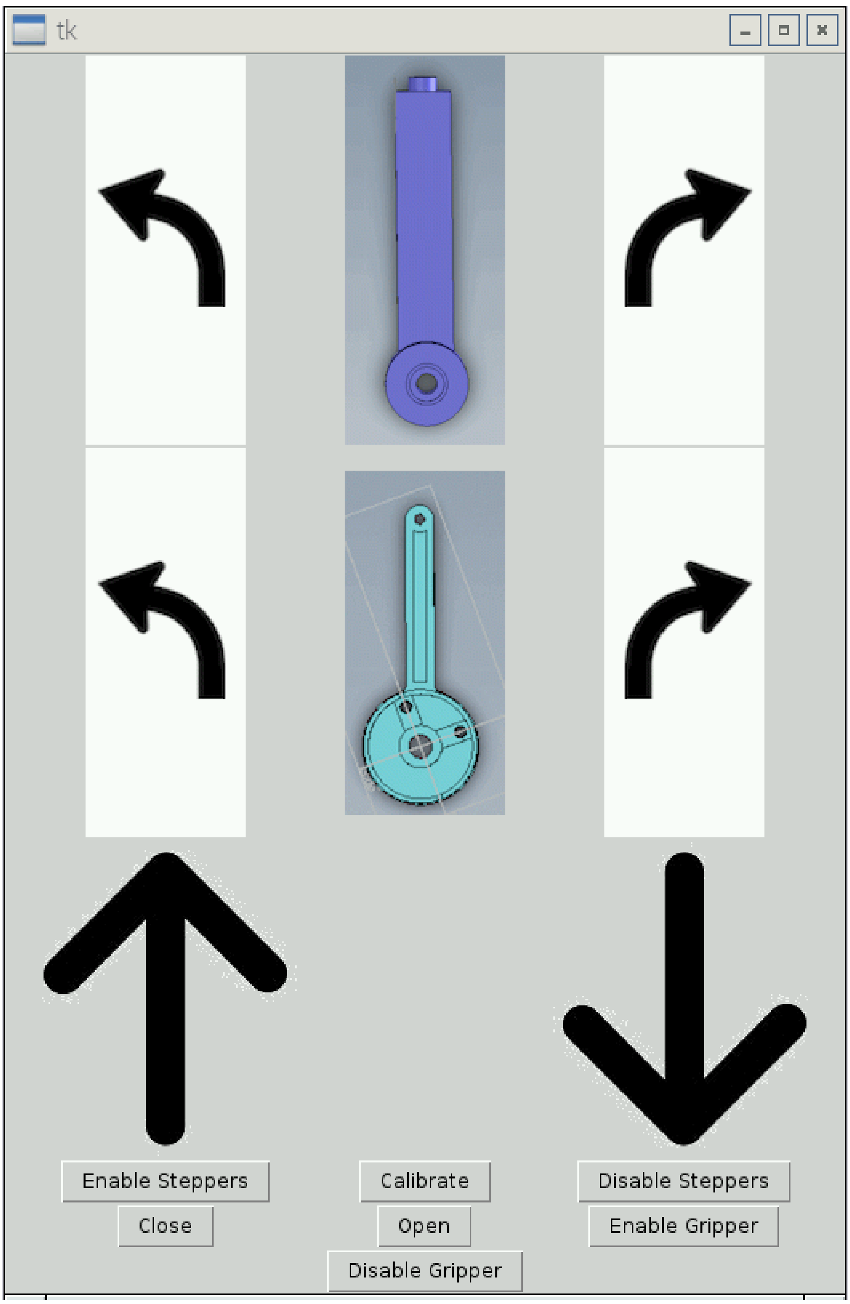
Figure 2.7: Solidworks Motion Analysis of Micro Motion II gripper (left); Gripper pinch strength of the human thumb and index finger (right).

3. Product Interactions

3.1 Software Application Overview

Our script works by talking the motor control boards which in turn tell the stepper motors how much to rotate. The stepper motors operate by the motor control board giving them a certain number of steps that they must rotate in order to achieve the desired distance. The commands are input with images from the GUI as shown in the figure below. The full script can be found in Appendix A.

Figure 3.1: Graphical User Interface



These arrows control the arm that is distal to the rotating drum.

These arrows control the arm that is proximal to the rotating drum.

These arrows control the rotation of the base plate which moves the arms up and down.

3.2 Product Demonstration

See demonstration video attached in portfolio.

4. Professionalism Standards and Social Impact

4.1 Manufacturability

The current role for bionic solutions is few-to-none because they are not insurable and a comparably small population compared to cardiovascular diseases. In terms of manufacturability, the goal is to create this device as an open-source minimal cost device. With the exception of the base plate, the gripper, and the motor, our micro motion II device can be made via injection molding. This allows for all of the rotational components to be made with low cost plastics at a near 100 percent yield.

4.2 Ethics

One of the most rewarding aspects of being an engineer in bioengineering is that it gives us the opportunity to help those in need. The ethical implications of this project are sound, as we are providing the disabled with an option to function as though they had a working hand of their own. There is no way this product could be used to harm, although there are concerns with recyclability and use of electricity, although we believe that with future research and development this could be mitigated.

4.3 Social Impact for the Disabled

Dr. Curtin explained that the psychological needs from isolation are quite large in people with tetraplegia. More so is the isolation from veterans who cannot afford to have personal care-takers at home. Most of these veterans live poorly on veteran housing and have limited financial means. Dr. Curtin explained that social integration is most easily done via computer games that are interactive across the internet. She has had success teaching them to play and interact via the game “Clash of

Clans," which requires a rudimentary single-touch input. A specific patient who has large intelligence is noted to have improved his psychological state via this game, as he cannot afford game consoles proctored toward tetraplegics. Such game consoles at $1000 are out of many people's price range with tetraplegia. Dr. Curtin asserts that there is a significant price constraint with our device, which is the main thing that prevents this product from being capable of helping those who are actually disabled. Fortunately, this is only a prototype device, and we remain optimistic that manufacturing a similar product would be far less expensive than the hefty price tag we've placed on the device right now.

4.3.1 Bringing the Product to the Disabled

Catherine Curtin, M.D. is an associate professor of surgery at the Stanford University Medical Center. Dr. Curtin's specialties are plastic and reconstructive surgery, specializing in hand, peripheral nerves, brachial plexus, and entrapment neuropathies. For the purpose of our project, Dr. Curtin was kind enough to explain her surgical experience on patients with tetraplegia at the Veterans Affairs Hospital in Palo Alto, CA.

4.3.2 Surgical Parts

Dr. Curtin explained that there are a variety of skills and abilities in patients with tetraplegia. Tetraplegia is resultant from spinal cord injuries. In the C1-C4 upper vertebrae, patients have no ability to use their hands and upper limbs. Patients with C5-C6 injuries are the most common patient group. These patients are unable to have fine motor control of their hands. However, C5-C6 patients are able to use a tenodesis pinch that allows for basic facilitation of movement. The tenodesis pinch is simply the flexis of the wrist that mechanically contracts the thumb to the index finger without muscular skeletal motion. One great feature of the tenodesis pinch is that it can be held for an unlimited duration, meaning that the patient would be able hold a grip on our device. Finally, the C7 spinal tetraplegics are able to have more control of gripping by rotating the pinch using supination and pronation. These patients are able to grip to a small extent some extent using natural pinch. Additionally, all patients C5 and below are able to grip a fork using a U-cuff wrist brace.

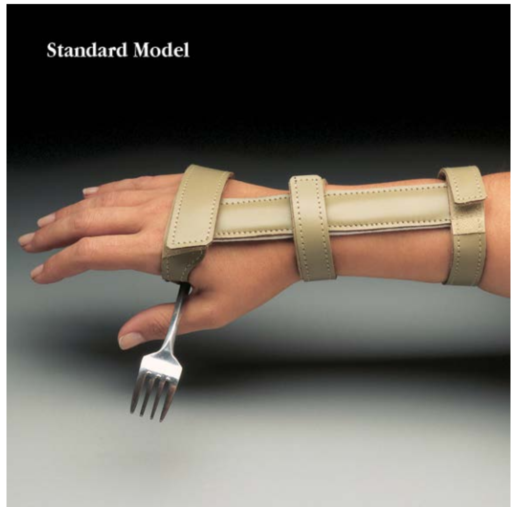


Figure 3.2: U-Cuff brace control via tenodesis pinch
https://ssl.cdn.ncmedical.com/items/fullsize/2012_04_17_12_29_56__8_NC35331_wc.jpg

4.3 Design Implementations

4.3.1 Input Functions

Dr. Curtin acknowledged that in terms of making this device feasible in the future, input to the micro motion II device is crucial. Those with C4 injuries and up are going to need a “sip and puff” maxial-facial input device. Meanwhile, those with C5 and lower injuries will be able to use a modified joystick that works in the 3rd dimension.

4.3.2 Output Functions

In terms of function, there are a variety of options Dr. Curtin referenced. To name a few: feeding oneself with a fork, iPad and digital device control, bowel care, and urinary catheters are a few to name. As mentioned previously, feeding oneself with a fork is accomplished well with the U-cuff brace. As far as the latter two are concerned, these require a high level of flexibility and precision on the device side. With this in mind, Dr. Curtin suggested that iPad and touch screen integration was the key to implementing our Micro Motion II prototype for future development.

5. Future Development and Potential Business Proposal

5.1 Base Model

In terms of the base model, the future improvements proposed will be to have a DC motor unit with an encoder. This will allow for the motors to properly move in the XY plane at the specified level should there be any slippage between gears. Additionally, we propose that there be a geared Z-axis, rather than a pulley system. This will allow for greater control in vertical motion, should the device take on more advanced and repetitive tasks than playing chess. For the two stepper motors on the XY plane, we will use belts, rather than Tungsten wire. This will allow for more freeing motion and decrease the amount of friction towards movement. Lastly, we propose to replace the pneumatic gripper joint with a solenoid. This will allow for the gripper to be automated and potentially move on its own.

5.2 Future Modifications

As we learned in our interview with Dr. Curtin, we propose to take an approach of implementing both input and more advanced output mechanisms. In terms of input, the would be benefit through maxial-facial inputs for C3 and above tetrapegics. Those with C4 and below tetraplegia will need to use a tenodesis pinch control input. This will be a response-based input that has the potential ability for angular rotation by the user’s forearm pronation.

5.3 Business Applications

In terms of potential business enterprise, the device may be able to work with iPads in the XY plane along the screen. The Z-axis could be used for pressure input. This is a huge market for the tetraplegics because many use iPads and other touchscreen devices for communication, entertainment, and calling an attendant.

5.4 Market Scalability

The scalability of this device largely depends on the cost. Our platform has the advantage of being easily modifiable with a multitude of motors that are mass manufactured. Also, if pieces could be injection molded in mass quantity, we could see the price being well under the $1000 ceiling Dr. Curtin defined. This ceiling exists because many accessories are not covered by health insurance as a necessity.

6. Conclusion

6.1 Opportunities for Future Improvements

It is our hope that the micro motion controller design will be further improved by future senior design groups at this university. Although we are pleased with what has been accomplished, there is still a lot of room for improvement and additional development. The next few sections describe some opportunities for future work.

6.2 Pulley system slippage

Although a number of issues with the cable system reduce its effectiveness in rotating the plate the rotating drum rests on, the main problem is slippage. Often times when the motor suddenly applies torque to the system, the band will slip, preventing the plate from moving at all. This is a huge design flaw of the product because it frequently prevents the device from moving in the z-axis, essentially preventing 3-D motion entirely. A number of mechanical changes could improve the current design. However, what we believe would be the most significant improvement would be to replace the cable pulley system with a rotating gear assembly.

6.3 Variation in rubber cable elasticity.

Varying or unpredictable elasticity in the pulley cable system prevents direct transfer of movement from the motor, introducing error. Some of the energy from the motor simply ends up being stored as tension in the cable. This is problematic in micro-motion controller design because it makes the system inefficient, and it would make any sort of motion readout inaccurate.

6.4 Replace pneumatic gripper with electronic gripper.

We originally chose a pneumatic gripper because of its simple binary operation. With the air compressor for the pneumatic gripper turned on, a simple on/off function is all that is necessary to open and close the gripper of the device. However, the on/off option presents a very serious problem. When the air tubes from the air compressor are connected to the gripper they sag onto the table surface, creating extra drag the motor must work against in order to rotate the arms of the assembly. In fact, when assembling the device, we soon found that the first pair of motors we were using did not provide sufficient torque to move the arms against this drag. We actually had to order new, more powerful motors to move the device, which in turn required us to drill new mounting holes in the rotating plate. The drag from these tubes required us to redesign the product with motors that were complete and utter overkill because they provide much more torque than would be necessary if they didn't have to work against the drag from the air tubes. They are very heavy, very large, and run so hot that they can seriously burn the user if they aren't being careful.

6.5 Add bearings to ease rotation drag.

Another improvement would be to add bearings where the shafts rotate within the posts. Currently, the device uses a rudimentary force-fit to rotate the plate that holds the rotating drum, which introduces drag into the system that wears down the plastic post over time. Bearings would essentially eliminate this source of wear.

6.6 Replace tungsten wires with toothed belt or gears.

Although there aren't any issues with elasticity with these wires, there are still problems with drag and slipping. When we tested and demonstrated the product, we ran into constant problems with the wires coming loose, migrating along the length of the motor shafts, or becoming disconnected entirely from the rotating drum. When it comes to motor control, it is best if everything in the system that requires movement is driven directly by the motor with as few intermediate components as possible that introduce drag into the system. Some possible solutions to this problem are the use of toothed belts instead of wires, or by introducing a gearing system that translates directly from the motor to the drums.

6.7 Future Design Projects

There is a lot of room for future senior design projects to build off of this project. The main feature that we would like to see added is to have a detailed graphical user interface that is programmed to automatically move chess pieces from one square to another without requiring the user to manually move the arm, activate the gripper, or move the piece. Additionally, we would hope to see future design teams move beyond the chess board application. The reason that we originally chose a chess board as our application for the device is that getting our device to move small chess pieces is a simple "stepping stone" towards having the device be practical for a disabled person who would want to use it for a variety of tasks.

Our group has already implemented a basic GUI to move the arms and activate the gripper, but it is far from what would be practical if a disabled person were to try to move the device. Currently, the motor that we are using is not capable of making small enough movements in order to be practical. During testing of the device with our GUI, we had a very hard time moving the chess pieces from one square to another. Our best effort took us about a minute and a half to pick up a piece, move the arm above the square we wanted to place the piece, and put the piece down without the piece falling over. This obviously falls far short of what the natural human hand is capable of doing, and is a clear indicator that there is still more work that needs to be done to make this device even remotely practical for a disabled person.

Our GUI operates through graphical images of both components of the arms with arrows representing which way they would rotate if the user was sitting behind the device (with the motor right next time to them on the base plate and the end with the gripper on the opposite side of the plate). [A simple drawing—a simpler version of the graphic on page 30 would work--to illustrate this operation would help here.] The user clicks the arrows for whichever way they want the arms and base plate to rotate. (A more detailed visual representation can be seen in the *Software Application Overview* section.) There is also a control button for the pneumatic gripper which opens and closes it. This GUI is still far from being user friendly for a number of reasons largely because it requires the user to actually *figure out* how to get the device to pick objects up for them. The user must look at the board and figure out through trial and error how to revolve and extend the arms in order to place the gripper over the chess piece. What we would like to see in the future is the implementation of some sort of programmed detection system that makes the device automatically move to where the piece is, and pick it up with just a simple input command. We would also like it to be able to automatically move the piece to a new square and place it without the piece ever falling over, as it often does in its current state.

6.8 Summary

Previously, we stated that our project goals were as follows:

- CAD – To create a workable model that achieves the design requirements
- Test – To pass our CAD design for physical stress and durability.
- 3D model – To prototype the mechanical functionality of the design
- Redesign – To make any necessary improvements to the foundation of our rotational controller add-on.

Over the course of this project we were able to design a project in Solidworks, model stress values using motion analysis, and create a tangible device using 3-D printing and attachable components. This covers the first 3 points listed; however, we did not have time to do any significant structural redesign, which means we fell short of the final point. However, this does not mean the project was a failure; we believe this project to be a resounding success. With limited time and resources, we were able to create a device that fulfilled its original design parameters: to pick up and move small chess pieces through the use of micro-motion design concepts. Moreover, this project leaves plenty of room for future design groups to learn from it and build upon it. We measure our success not just by the end-product we created, but by the potential we have introduced for future design projects at this university by presenting this idea.

6.9 Learning Opportunity

One of the many reasons that working on this project was such a great learning opportunity was that it gave us hands-on experience dealing with practical problems and constraints that we had to overcome to get the job done. We had to take an original product that fell short of our desired design parameters and modify it to meet them. It was a unique experience which encompassed everything we learned in the classrooms as engineers and applied it to the real world.

6.10 Undergraduate Course Applicability

PHYS 31: Basic understanding of friction, force, moments of inertia, and torque.

MECH 10: Use of Solidworks for designing and doing motion analysis for stress calculations.

ELEN 50: Basic use of electric circuits to power DC motors and motor control boards.

COEN 10/11: Basic programming skills as the basis for coding in Python.

7. Bibliography

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Appendix A: GUI Code and Operations Map

```
from Tkinter import *
from PIL import ImageTk, Image
import time
from Phidgets.PhidgetException import *
from Phidgets.PhidgetLibrary import *
from Phidgets.Devices.Stepper import *
from Phidgets.Devices.MotorControl import *
import RPi.GPIO as GPIO

GPIO.setmode(GPIO.BCM)
GPIO.setup(4, GPIO.OUT)
GPIO.setup(5, GPIO.OUT)

global flag
flag = False

global fa
global ua

# Calibrate Steppers
class Init():
    def cal(self):
        global fa
        global ua
        for i in range(2):
            try:
                stepper.setEngaged(i,True)
                print('Motor %i engaged. Calibrating...' % (i+1))
            except PhidgetException as e:
                print ('Phidget Exception %i: %s' % (e.code, e.detail))
                exit(1)

        try:
            stepper.setTargetPosition(0, 400)
        except PhidgetException as e:
            print ('Phidget Exception %i: %s' % (e.code, e.detail))
            exit(1)

        try:
            stepper.setTargetPosition(1, -400)
        except PhidgetException as e:
            print ('Phidget Exception %i: %s' % (e.code, e.detail))
            exit(1)

        time.sleep(5)

        for i in range(2):
            try:
                stepper.setCurrentPosition(i, 0)
                stepper.setEngaged(i, False)
                print('Motor %i Calibrated.' % (i+1))
            except PhidgetException as e:
                print ('Phidget Exception %i: %s' % (e.code, e.detail))
```

```
                exit(1)
        fa = 0
        ua = 0

# Create
global stepper
try:
    stepper = Stepper()
except RuntimeError as e:
    print("Runtime Error: %s" % e.message)

# Open
try:
    stepper.openPhidget()
except PhidgetException as e:
    print ('Phidget Exception %i: %s' % (e.code, e.detail))
    exit(1)

# Create
global DC
try:
    DC = MotorControl()
except RuntimeError as e:
    print("Runtime Error: %s" % e.message)

# Open
try:
    DC.openPhidget()
except PhidgetException as e:
    print ('Phidget Exception %i: %s' % (e.code, e.detail))
    exit(1)



root = Tk()




class Forearm():
    def right(self):
        fa = fa + 1
        stepper.setTargetPosition(2, fa)

    def left(self):
        fa = fa-1
        stepper.setTargetPosition(2, fa)

class Uarm():
    def right(self):
        ua = ua + 1
        stepper.setTargetPosition(1, ua)
```

```
    def left(self):
        ua = ua - 1
        stepper.setTargetPosition(1, ua)

class StepEn():

    def En(self):
        print('Engaging')
        for i in range(2):
            try:
                stepper.setEngaged(i, True)
                print('Motor %i engaged.' % (i+1))
            except PhidgetException as e:
                print ('Phidget Exception %i: %s' % (e.code, e.detail))
                exit(1)

    def Dis(self):
        print('Disengaging')
        for i in range(2):
            try:
                stepper.setEngaged(i, False)
                print('Motor %i disengaged.' % (i+1))
            except PhidgetException as e:
                print ('Phidget Exception %i: %s' % (e.code, e.detail))
                exit(1)


class DCM():

    def on(self):
        try:
            DC.setVelocity(0, 100)
        except PhidgetException as e:
            print ('Phidget Exception %i: %s' % (e.code, e.detail))
            exit(1)
        time.sleep(0.5)
        try:
            DC.setVelocity(0, 0)
        except PhidgetException as e:
            print ('Phidget Exception %i: %s' % (e.code, e.detail))
            exit(1)



    def rev(self):
        DC.setVelocity(0, -100)
        time.sleep(0.5)
        DC.setVelocity(0, 0)
        print('Motor On')

class Grip:
    def close(self):
        GPIO.output(4, True)

    def enable(self):
```

```
    GPIO.output(5, True)

    def open(self):
    GPIO.output(4, False)

    def disable(self):
    GPIO.output(5, False)


class App:
    def __init__(self, root, Arrow, r, c, motor, dir):
        self.root = root
        self.mouse_pressed = False
        self.f = Arrow
        self.f.grid(row=r, column=c)
        self.f.bind("<ButtonPress-1>", self.OnMouseDown)
        self.f.bind("<ButtonRelease-1>", self.OnMouseUp)
        self.motor = motor
        self.dir = dir



    def do_work(self):
        global fa
        global ua
        global stepper
        global DC
        print(self.dir)
        print(self.motor)
        if self.dir == 0 and self.motor == 0:
            ua = ua-5
            stepper.setTargetPosition(0, ua)
            print(ua)
        elif self.dir == 1 and self.motor == 0:
            ua = ua+5
            stepper.setTargetPosition(0, ua)
            print(ua)
        elif self.dir == 0 and self.motor == 1:
            fa = fa-5
            stepper.setTargetPosition(1, fa)
            print(fa)
        elif self.dir == 1 and self.motor == 1:
            fa = fa+5
            stepper.setTargetPosition(1, fa)
            print(fa)
        elif self.dir == 0 and self.motor == 2:
            DC.setVelocity(0, 40)
            time.sleep(.1)
            DC.setVelocity(0,0)
        elif self.dir == 1 and self.motor == 2:
            DC.setVelocity(0, -40)
            time.sleep(.1)
            DC.setVelocity(0,0)
        x = self.root.winfo_pointerx()
        y = self.root.winfo_pointery()
        print "button is being pressed... %s/%s" % (x, y)
```

```
    def OnMouseDown(self, event):
        self.mouse_pressed = True
        self.poll()

    def OnMouseUp(self, event):
        self.root.after_cancel(self.after_id)

    def poll(self):
        if self.mouse_pressed:
            self.do_work()
            self.after_id = self.root.after(25, self.poll)



fImage = Image.open('forearm.gif')
fphoto=ImageTk.PhotoImage(fImage)
forearm = Label(image=fphoto)

rimage = Image.open('RT.gif')
limage = Image.open('LT.gif')
rphoto=ImageTk.PhotoImage(rimage)
lphoto=ImageTk.PhotoImage(limage)
LT = Label(image=lphoto)
RT = Label(image=rphoto)

r1image = Image.open('RT1.gif')
l1image = Image.open('LT1.gif')
r1photo=ImageTk.PhotoImage(r1image)
l1photo=ImageTk.PhotoImage(l1image)
LT1 = Label(image=l1photo)
RT1 = Label(image=r1photo)

UImage = Image.open("Uarm.gif")
Uphoto=ImageTk.PhotoImage(UImage)
Uarm = Label(image=Uphoto)
Uarm.grid(row=1, column=1)

DTImage = Image.open("DN.gif")
DTphoto=ImageTk.PhotoImage(DTImage)
DT = Label(image=DTphoto)
DT.grid(row=2, column=2)

UPImage = Image.open('UP.gif')
UPphoto=ImageTk.PhotoImage(UPImage)
UP = Label(image=UPphoto)
UP.grid(row=2, column=0)

forearm.grid(row=0, column=1)

app = App(root, LT, 0, 0, 1, 0)
app1 = App(root, RT, 0, 2, 1, 1)
app2 = App(root, LT1, 1, 0, 0, 0)
```

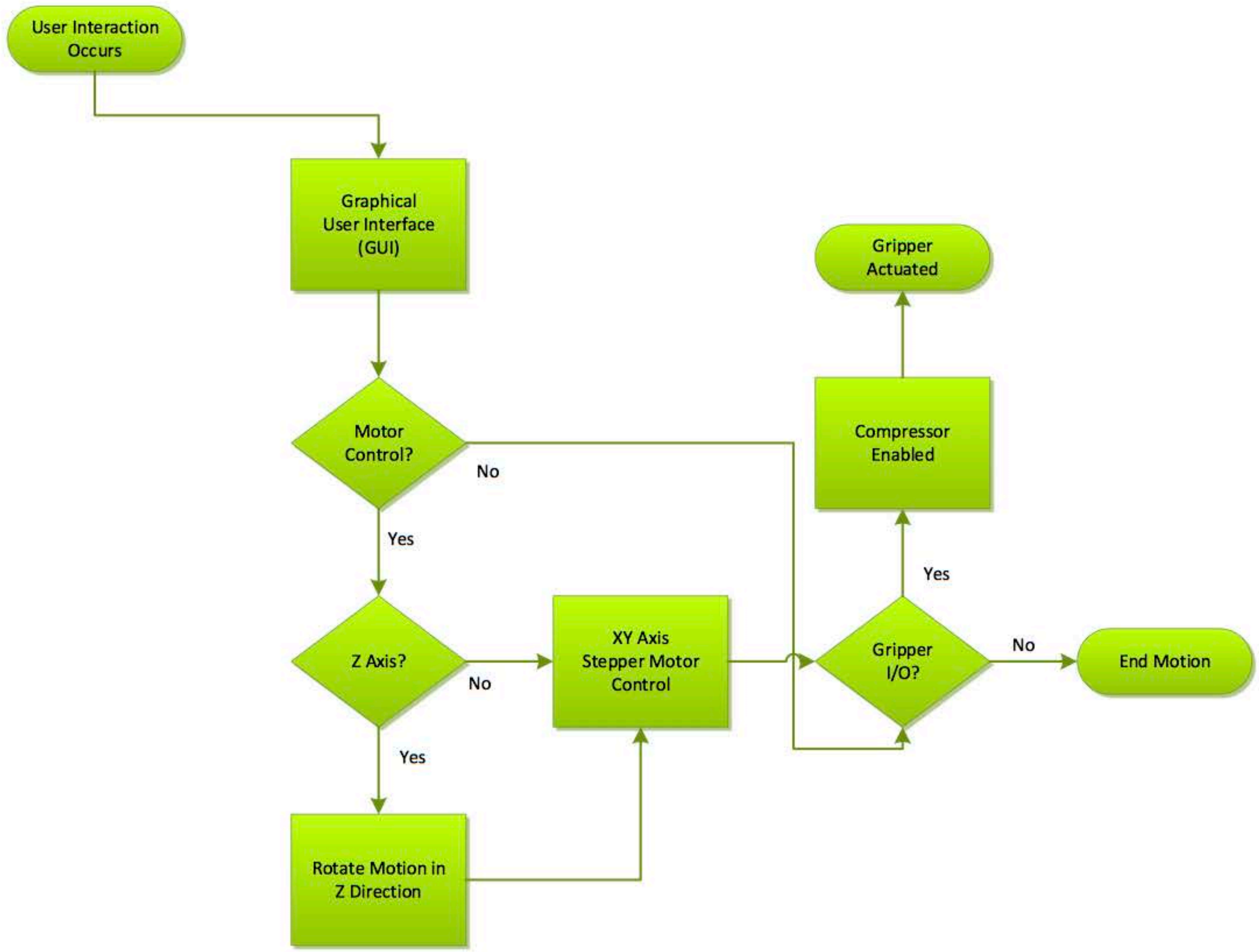
```
app3 = App(root, RT1, 1, 2, 0, 1)
app4 = App(root, DT, 2, 2, 2, 0)
app5 = App(root, UP, 2, 0, 2, 1)

motor = DCM()
gripper = Grip()
enabler = StepEn()
start = Init()

#Button(root, text='Down', command=motor.on).grid(row=2, column=0)
#Button(root, text='Up', command=motor.rev).grid(row=2, column=2)
Button(root, text='Calibrate', command=start.cal).grid(row=3, column=1)
Button(root, text='Enable Steppers', command=enabler.En).grid(row=3,
column=0)
Button(root, text='Disable Steppers', command=enabler.Dis).grid(row=3,
column=2)
Button(root, text='Close', command=gripper.close).grid(row=4, column=0)
Button(root, text='Open', command=gripper.open).grid(row=4, column=1)
Button(root, text='Enable Gripper', command=gripper.enable).grid(row=4,
column=2)
Button(root, text='Disable Gripper', command=gripper.disable).grid(row=5,
column=1)

start.cal()
enabler.En()


#RTB = Button(root, image=rimage, width=100, height=243, bd=0, command=call1)
root.mainloop()
```



User Interaction Occurs
Graphical User Interface (GUI)
Motor Control?
No
Yes
Z Axis?
No
Yes
Rotate Motion in Z Direction
XY Axis Stepper Motor Control
Gripper Actuated
Compressor Enabled
Yes
Gripper I/O?
No
End Motion

Appendix B: Project Management Data

B.1 Budget

Item	Supplier	Cost
DC Power Supply	McMaster	$80
Mechanical Hardware -- (4 Gears + Bushings)	McMaster	$100
Mockup of Intuitive Surgical Inc. Micro-Controller Platform	ProtoLabs	$300
Motor Bracket & Base Plate	ProtoLabs	$500
Misc Electrical Wiring	McMaster	$80
Mounting Hardware	McMaster	$40
Gripper Prototype	ProtoLabs	$300
Spring (Gripper)	McMaster	$15
Solenoid (x2)	McMaster	$80
Total	------------	$1495

B.2 Group Management

Micromotion Controller: Add-on			**Week**							
Tasks		**Owner**	WQ 8	WQ 9	WQ 10	WQ 11	SQ 1	SQ 2	SQ 3	SQ 4
Budget		Team								
CAD										
	Mockup CAD	Steve								
	Baseplate CAD	Michael								
	Mounting Bracket CAD	Bergren								
Mechanical Analysis										
	Motor-Gear Analysis	Team								
	Simulated Motion	Team								
Deepak										
	Bill of Materials	Michael								
	Submit Parts Order	Steve								
Project Build										
	Organize/Inspect Parts	Bergren								
	Mesh Assembly	Team								
	Deepak	Team								
Data										
	Electrical Tests	Steve & Bergren								
	Range of Motion	Team								
	Stress Test (CAD)	Michael								

Appendix C: Parts Used

C.1 Bill of Materials

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	10Maxon Plate_Micromo	Main Plate	1
2	10Pulley_drum_1	Bottom Drum and Link	1
3	10STOCK_DRIVE_PRODUCTS_FLANGED BEARING_A 7Y55-F3118	.3125 OD .1915 ID Flanged Bearing	6
4	10Pulley_drum_2	Top Drum	1
5	10Link_1	Forearm Link	1
6	10END_PIVOT	Plate Pivot and Large Pulley Mount	1
7	10Rope	Forearm Belt	1
8	10SHAFT_MAIN	Drum and Link Axle	2
9	93365A122	#4 Long Ultrasert	5
10	93365A132	#6 Long Ultrasert	4
11	10POST	Support Post	2
12	Large pulley		1
13	SCHUNK-- RH-901 K-FS OC 5		1
14	SCHUNK--Grundbacke RH 901		2
15	Motor	Phidgets 3260_0	1
16	Small pulley		1
17	END_PIVOT2	Right Side Pivot	1
18	square key_ai	0.09375x0.09375x0.5	1
19	Motor shaft	{Software-only part	part of Motor}
20	pan cross head_am		2
21	CR-PHMS 0.112-40x0.25x0.25-N	#4-40 x 3/8	1
22	5225K559	4mm OD Tubing PTC Fitting	2
23	SCHUNK-0309476 Drehdeckel MV 15 radialer Kabelabgang	MV15 Radial Cover	2
24	10SCHUNK-0309502 Schalldämpfer M5	Silencer	2
25	10SCHUNK-0309262 3_2-Ventilpatrone MV 15 - Druck	MV15 Valve Cartridge	2
26	10SCHUNK-0309298 Schwenkverschraubung SV 15-SP-ID4-M5	MV15 Banjo Fitting	2
27	pan cross head_ai	#4-40x1	4
28	CR-PHMS 0.138-32x0.25x0.25-N	#6-32x1/4	5
29	pan cross head_ai	#6-32x3/8	4
30	5225K77	4mm OD PTC T-Fitting	1
31	52065K529	4mm OD PTC Female M5	2
32	flat washer type a selected narrow_ai	#4 Washer	1
33	Belt3-4^Assem9	1/8" O-ring Belt	1

34	flat washer type b wide_ai	#6 Fender Washer	1
35	Base Panel		1
36	Motor Bracket		1
37	Valve Bracket		2
38	Air Tube 1^Assem9	4mm OD Tubing	1
39	Air Tube 2^Assem9	4mm OD Tubing	1
40	Air Tube 3^Assem9	4mm OD Tubing	1
41	Long Capstan		2
42	Foot		4
43	CR-PHMS 0.112-40x1x1-N	#4-40 x 1"	2
44	MSHXNUT 0.112-40-S-N	#4 Nut	2
45	Preferred Narrow FW 0.164	#8 Washer	2
46	B18.6.7M - M2.5 x 0.45 x 6 Type I Cross Recessed PHMS --6N	M2.5 x 0.45 x 6 Screw	4
47	Motor 4		2
48	Fixed Carriage		1
49	Finger 2	Gripper Finger	2
50	Foam insert		2