# Motion Stage for Optical Coherence Tomography

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**Table of Contents**

## *Motion Stage for Optical Coherence Tomography*

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### Abstract

Optical coherence tomography is a useful diagnostic tool in detecting conditions in the eye. In clinical settings, patients are often unable to move their eyes with the fine adjustment that optical coherence tomography requires to obtain images precisely. Consequently, the OCT machine, which is rather bulky, has to be moved. This task involves fine range motion in three dimensions (X, Y, and Z) as well as rotation around a central axis. To facilitate this, our design team used a fine range cross table capable of fine resolution movement in two directions (X and Y) along with a vertical table capable of motion in the Z-direction. For the rotational component, we used a spindle mechanism with a track.

### Background

Optical coherence tomography (OCT) is the ideal imaging modality when it comes to diagnosing degenerative conditions of the eye, such as macular degeneration. It is non-invasive, requires no special preparation either on the patients' or clinicians' part, and does not harm the patient in any way due to radiation. OCT uses the principle of interferometry to scan the

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patient's eye, so precision is an important factor during image acquisition (the broadbeam laser source measures in the range of 1000s of nanometers)[1].

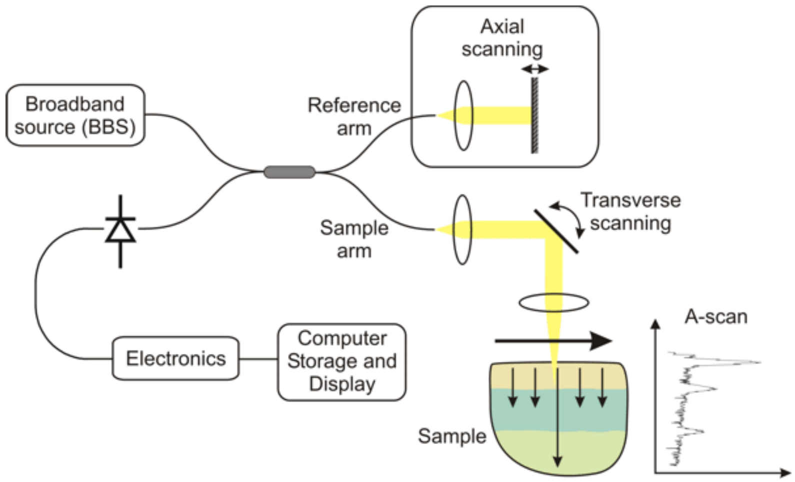


**Figure 1**: Schematic of Optical Coherence Tomography that demonstrates how important proper positioning of the laser system is (obel.ee.uwa.edu.au).

The clinical relevance of OCT is enormous, especially to older patients, who tend to have many conditions affecting their eyes. Many of the patients at the clinic tend to be older, and may have difficulties performing the fine adjustments in position required for the technician to obtain the proper image. The situation is further compounded by the fact that the OCT machines themselves are rather bulky and cannot be easily moved. In addition, in imaging situations where the subjects are unable to move (as in animal tests) because they are sedated, it is difficult to move the machine to accommodate the new subject.

**Introduction**

Technicians operating the OCT system find it difficult to maneuver these machines precisely in the case patients are not able to.  The OCT machines, as shown below, are quite large and cannot be easily moved by the technician.


**Figure 1:** Stratus Model OCT Machine, Zeiss.

**Figure 2:** The Stratus model of the OCT incorporates some of the functionality needed.  It uses a joystick mechanism which allows the technician to “slide” the machine into position. This joystick is completely mechanical, using ball bearings.

In terms of ergonomics, the joystick offers a friendly user interface because its function is intuitive.  Our client would like for us to duplicate this functionality for the Cirrus Model.  The Cirrus model does have limited motion capabilities, but the movement is

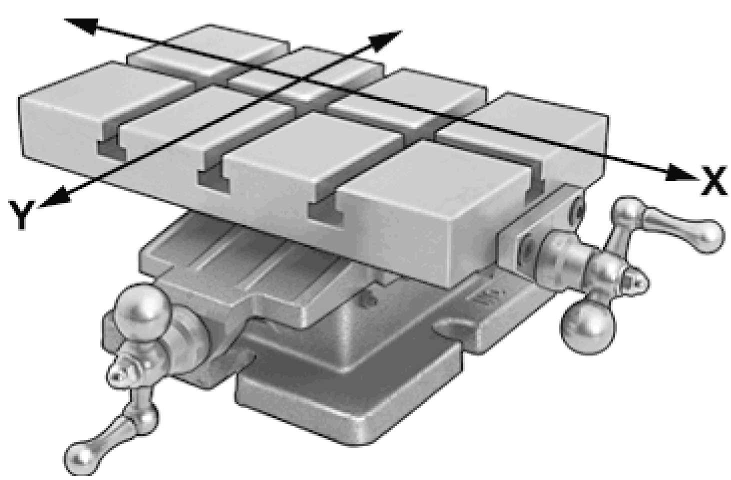


**Figure 3:** Fine-Adjust Cross-Slide Table, McMaster-Carr, http://www.mcmaster.com/

controlled through the computer and requires the technician to concentrate on how the machine is moving while performing tasks on the computer interface (the control interface are arrow buttons; when clicked on, the chin rest shifts). This diversion of attention on the clinician's part could result in improper positioning and ineffective runs of image acquisition.

**Specifications**

There are four degrees of motion associated with the task: horizontal translation (X), lateral translation (Y), vertical motion (Z), and rotation around a central axis.

The fine-adjust cross-slide table depicted above is capable of fine resolution movement in two of these directions: X and Y. The cranks are incremented by 0.02 mm and thus facilitate more than the value of the precision specified by the client.

**Discussion**

**Alternative Designs**

Market searches did not reveal any devices suitable to this application. Therefore, we adapted several designs for the motion stage. The first design consists of an overhead arm that would be attached to a wall in the procedure room. The design mirrors overhead arms used in dentist's office to hold x-ray machines and in hospitals that hold overhead lights. The configuration can be seen in Figure 4**.** The joint at the wall allows motion in the xy plane and the joint connecting the two beams allows motion in the xz plane. The cage seen at the bottom of the arm would hold the camera at the joint attaching the catch to the arm would allow for additional movement. This design meets the requirements of three degrees of motion as well as rotational movement but allows for only coarse adjustment. The nature of ocular imaging requires precise alignment of the camera with the retina, which could be difficult with this device. Additionally, the monetary expense of buying all the parts and the amount of time required to assemble the device decrease its practicality for application. The second design considered involves a precision slide with a screw bearing as pictured in Figure 5. One slide would provide motion in one direction, either x or y. It would be necessary to construct or purchase a xy table so that two slides could be used at the same time to provide movement in the x and y directions. The ease of motion control for the device makes the design user friendly and precise enough for use with the imaging camera. However, like the overhead arm, the cost of purchasing all the necessary parts to construct a complete motion

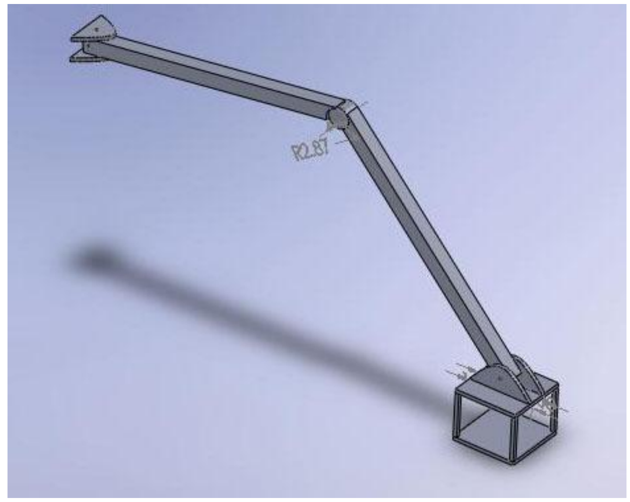

**Figure 4:** Overhead arm design consists of a cage to hold the camera and three joints to allow translational movement.

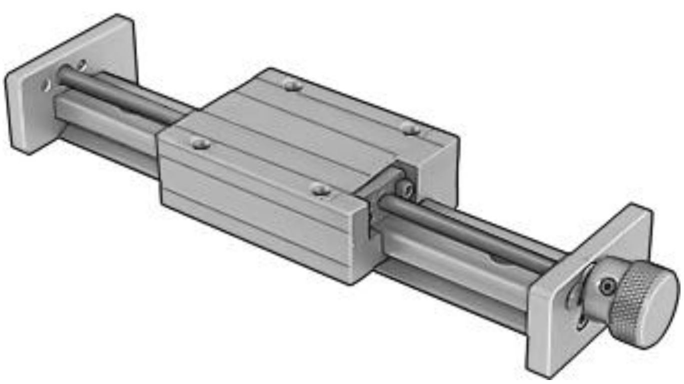

**Figure 5:** The precision slide with a screw bearing provides motion in one direction. The platform in the middle moves as the screw is turned by the knob on the right.

stage is prohibitive. Moreover, the device does not easily allow for rotational motion and a considerable amount of torque would be generated as the camera's center of mass moves farther away from the center of mass of the motion stage.

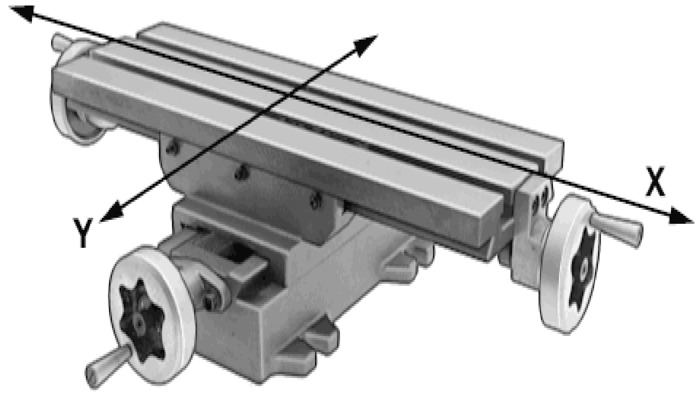


**Figure 6:** The motion stage device has two axes of rotation. They are shown in the picture as the x and y direction. The position of the stage is controlled by the three hand cranks.

**Final Design**

The final design considered involves a fine adjust cross slide table as in Figure 6. It is similar to the slides in the second design but the table possesses x and y motion without any modification. The cranks are used to move the table with a precision of 0.02 m. These cranks meet the client's specifications for ease of use. Again, as with the previous design, the table needs modification to accommodate rotational motion. The weight of the cross slide table is also rather large (at 80lbs) which may cause undesired stress on the table on which the motion stage device is placed.

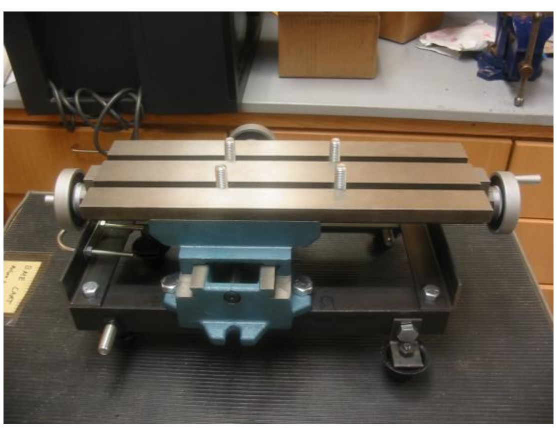

**Figure 7**: Image of final design. The bolts protruding from the table edge will eventually be attached to the bottom of the camera.

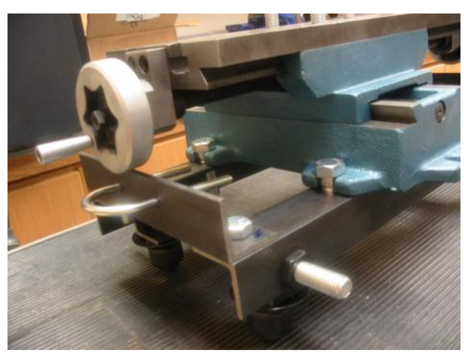

**Figure 8**: ¾ view of the final design from the side depicting the crank mechanism used to move the platform and the U-bolt required to facilitate rotation

**Discussion of Alternative Designs**

**Table 1:** Design Matrix Detailing Critical Criteria in Design of Cross-Table, please see above for discussion of pros and cons

| Design Constraints | Weight | Overhead Arm | Precision Frelon Plain-Bearing Slides with Lead Screw | Fine-Adjust Cross-Slide Tables |
|---|---|---|---|---|
| Degrees of Motion | 20 | 19 | 17 | 17 |
| Ergonomics | 15 | 3 | 10 | 13 |
| Load Bearing | 20 | 5 | 15 | 20 |
| Ease of Rotation | 10 | 10 | 5 | 7 |
| Precision | 15 | 2 | 15 | 14 |
| Cost | 20 | 5 | 10 | 19 |
| Total | 100 | 44 | 72 | **90** |

The choice for the design was made based on the fact that a fine-adjust cross slide table fulfills the horizontal movement requirements without any modifications. This combined with the table used at the lab capable of vertical motion satisfies every required degree of freedom except for rotation. The cross slide table chosen is considerably more precise than required; however, its operation is very simple and smooth. It is able to easily support the weight of the ocular imaging machine, as it is capable of bearing two times its weight, and is relatively inexpensive at $285. Some of the disadvantages of this choice are that it has no tilt option, it weighs 60 pounds, and it requires modifications to be made in order to enable the final degree of freedom, rotation.  Yet, it is still the best choice considering that tilt is not important to the operators and that even the combined weight of the table, the imaging device, and the additional rotation equipment is easily supported by the lab's table.

Perhaps the most important benefit of the cross slide table design is how easily it can be modified to better fit the needs of the clinicians.  The table, as seen in Figure 6, has hand cranks for movement in the horizontal plane that can easily be fit with a motor and controlled electronically, perhaps with a joystick.  As for rotation about a point in front of the imaging device, our final design incorporated inverted ball bearings for easy movement about the focus point.  The bearings, as seen in Figure 7, are each capable of supporting 250 pounds, and our final prototype uses four of them.  They are bolted to a rectangular angle iron frame made of steel, with one bearing positioned at each corner of the frame.  The cross slide table is then bolted to the frame, allowing it to slide.  In order to use this sliding capability to allow for rotation, a vertical pole will be secured to the lab's table, and the front of the slide cross slide device will be attached to the pole with a U-bolt.  This will hold the front of the table fixed, and the bearings will allow rotation about an arc.  Finally, imaging device will either be attached to the cross slide table with bolts or by sitting in a frame of angle iron.  The device including the angle iron frame with bearings attached and the cross slide table can be seen in Figure 8.

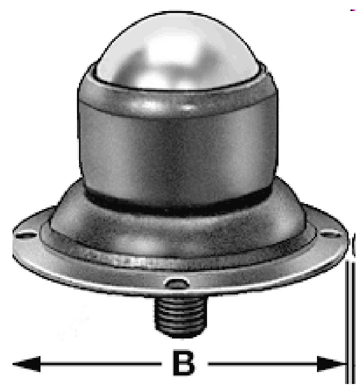


**Figure 9:** Ball Bearing, load capacity 250 lbs

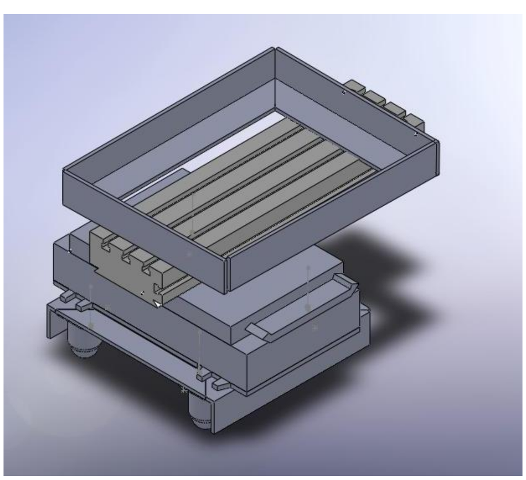

**Figure 10:** Solidworks Rendering of Final Design, ¾ view from side.

The base is depicted with the ball bearings shown.  The cross-slide table is placed on the base and bolted with 5/8" bolts onto the base frame.  The top surface of the cross-slide table is attached to a frame which supports the weight of the camera.

In choosing the design, we gave the number of degrees of motion and load capacity criteria the largest amount of weight. This was because the most important function of our device would have to be its ability to facilitate movement in the x-y plane, vertical plane, and rotation.

As shown, our final design meets all the specifications set by the client: the precision of the movements required in the horizontal plane, the motion required in the vertical plane (supplied by the Zeiss table already in operation at the clinic) and the rotation.

**Table 2:** Final Design Specifications

| | |
|---|---|
| **Ball Bearings** | **Load Capacity 250 lbs/each** |
| **Frame** | **Angle Iron Construct, 1.75" thick** |
| **Cross Slide Table** | **Platform size 18 5/8" X 6 3/16"**<br>**Load capacity 150 lbs**<br>**Table travel 12" X 8"**<br>**Height 5 3/16"** |
| **Bolts connecting frame to table** | **5/8"** |

**Future Work: Improving device safety and usability**

Going forward, changes will be made to the motion stage to improve the safety of the device, first and foremost. The prototype used a temporary clamping system to fix the axis of rotation to the front of the table. For use in a clinical setting, however, it is crucial that this axis be fixed in a more permanent manner. Because of the massiveness of the camera and x-y sliding table, the rotational axis must be able to withstand the forces due to the inertial mass of the pair rotating about it. Any deficiencies in this axis will pose a safety hazard to the subject, as the camera and table, together weighing over 150 lbs., could fall upon the subject in the event of failure and cause severe injury.

To protect both user and operator, the rotation of the device must be mechanically restricted to prevent the device from falling off the table due to over-rotation. Similarly, motion in both the x and y directions must be mechanically constrained so as to keep the center of gravity of the device within the wheel base. Should the center of gravity be extended outside the base, the device could potentially tip over and fall onto either the subject or operator causing severe injury.

Improvements will also be made to improve the device's precision and usability. The prototype developed this semester allows the user to accurately move the camera in the x-y plane in increments of .02 mm. The precision of the rotational control, however, is not nearly as refined as in the precision of control in the x-y plane. Ideally, the device would offer precise control of rotation to within 1°. A worm drive will be used to rotate the device in small increments. In addition to improving the precision of control over rotation, a worm drive will also mechanically prevent unintentional rotation of the device due to inadvertent contact with the device.

To further improve the precision of movement, improve the overall usability of the device and to add redundancy to the mechanical constraints on the device's motion, all of the

**Figure 11:** Joystick to control the cross-slide table

mechanical components of the device will be coupled to electronics to allow the device to be electromechanically controlled by the user. Presently, the device has separate controls for each of its degrees of motion. It has a hand crank to control motion in the x-direction, another hand crank located on a different portion of the device to control motion in the y-direction, and rotation is using a handle at the device's rear. This will make the device more convenient and efficient to use. In the future, all of these controls will be consolidated into a single joystick control interface. Not only will this consolidation improve usability, but also, it will allow for the precision of motion to be varied, to some degree, programmatically by varying the degree of electrical signaling to the motors. Finally, the electronic portion of the control system can also be used to impose constraints on the extent of the device's motion. This would provide a redundant safety system to the mechanical safety measures already in place. Since device safety is of paramount concern, a second system of preventing over-rotation and tipping is highly desirable.

**Device Performance Evaluation**

To assess the usability of our device and to determine whether it actually improves the quality of images captured by the OCT camera, some type of assessment survey will have to be developed and administered to both current and new users of the devices. To make an effective assessment of the positioning device design, it will be necessary to compare the time and number of attempts required by current, experienced camera operators to position the subject appropriately and obtain a quality image, to the time and attempts required by the same operators with the aid of this positioning device. In addition, feedback as to the responsiveness of the control system and would be elicited so as to make improvements that would make the device easier to use and more efficient at producing quality images. Such a survey would be particularly beneficial in programming of the electromechanical control system to be neither overly sensitive nor sluggish and unresponsive.

**Ethical Concerns/Usability**

Our design involved no major ethical concerns during construction. However, since the device will be used in a clinical setting, it is important to consider how the device will interact both with the personnel and the patients involved.

During animal imaging studies, the animal will be anesthetized. Therefore, the travel of the table should be the only motion involved. During the study, the animal's safety should not be compromised. We can ensure this by constraining the table's motion so that it is slow. This also applies to clinical procedures involving people.

Another concern is how the device will function in a clinical environment. When considering human factors, one has to account for how easily the device is operated. Thus, intuitiveness of the device's function is very important. As specified by the client, a joystick mechanism would be appreciated for this purpose. The user interface thus becomes graphical and requires no further instruction (the current crank mechanism may be harder to implement). Future work will involve testing to determine which method works for clinicians.

**Conclusions**

This semester, our team designed a functional prototype that is capable of providing the precision required to move a motion stage for the OCT machine. We provide the X-Y resolution through the cross-slide table, the rotation through the use of ball-bearings and frame coupled to a U-bolt pivot point, and vertical motion through the Zeiss table already available in the clinic. Future work will involve testing to determine how well the user is able to interface with the device.

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September 17, 2008
Thomas Fleming
William Stanford
Dan Frost
Vidhya Raju

**Positioning/alignment device for ophthalmic scanning laser systems**

**Function**

The device must be designed to position the 80lb. Cirrus-OCT ocular imaging device currently in use by the Ophthalmology clinic. While the clinic's current positioning system is capable of crudely positioning the OCT camera in the vicinity of the eye, it lacks fine positioning capability. This device we design must be able to refine the position of the OCT device by distances as small as a few millimeters. It must be able to position the camera in the horizontal plane, tilt the camera, and rotate the camera. The user interface for such fine movements must be simple, accurate, and repeatable, as is the joystick positioning device used for a different model of OCT camera currently in use at the clinic.

**Client requirements:**

- Height, angle, and tilt, and rotation adjustments
- Fine tuning of positioning
- OCT must be 2 inches away from the eye
- Preference for a joystick to adjust the instrument
- Must be used for both human and animal optical imaging
- Must be a device for supporting the OCT and not for positioning the head, for safety concerns

**1. Physical and Operational Characteristics**

a. *Performance requirements*: The device should be able to position the OCT at the correct height, angle, rotation, and tilt for proper optical imaging. The device will be used every time that the OCT is used, because the proper alignment will be different each time. It must support the weight of OCT and be able to lock into place once proper alignment is achieved.

b. *Safety*: The main safety concern is that the device must be able to support the weight of the OCT. The inability of the device to do this could cause injuries due to the falling or breaking of equipment.

c. *Accuracy and Reliability*:  The device must be extremely accurate in order to be able to precisely align with the location of the eye that is to be imaged.  This means that the device must be able to make very fine movements in height, angle, rotation, and tilt.  Repeatability of positioning is desirable for when patients are imaged more than once.

d. *Life in Service*:  The device will be used multiple times per day.  It does not need to be designed to be mobile, because it will stay with the OCT at all times.

e. *Shelf Life*:  The Ophthalmology Clinic uses the Cirrus-OCT on a daily basis.  Because of this and its 80 lb. size, the Cirrus unit remains on the table in the clinic's imaging room at all times.  Because transporting the Cirrus unit off the table is difficult due to its bulk, our positioning unit will presumably remain beneath the Cirrus unit at all times, both during periods of use and non-use.  Therefore, its shelf environment is the same as its operating environment and it must be designed to withstand any harsh conditions of this persistent environment.

f. *Operating Environment*:  The imaging room does not have any water sources.  It is kept at a room temperature and humidity typical of most clinical environments.  Patients and doctors do enter and exit the room frequently, and doctors will presumably be using the unit multiple times per day, so the unit will most likely be exposed to a significant number of low intensity stresses on a daily bases, and more intense stresses on a less frequent basis.

g. *Ergonomics*:  The device's motion control interface must be user friendly and not cause stress to a frequent user.  Both patients and doctors will be in close proximity to the device's moving parts.  Therefore, any moving parts must be contained so as to avoid pinching or crushing of patients' and doctors' extremities should inadvertent contact occur.

h. *Size*:  There is no strict restriction on weight as the unit will be stationary.   In terms of spatial dimensions, it must either have a footprint small enough to fit on the imaging room's camera table or it must be a stand-alone unit small enough to fit into the 8' x 8' imaging room.

i. *Weight*: The weight of the device must be light enough to allow rotation and movement in the desired directions.  If the device is too heavy, the operator will have to apply a great amount of force to move the position, eliminating any chance for fine adjustments.

j. *Materials*:  The materials used to construct the positioned will have to be strong enough to hold 80 lbs.  They should be capable withstanding year of use.  They should be of a weight that fits with the requirements presented in the weight category.

k. *Aesthetics*:  The design of the device should allow for easy use by any operator.  All adjustment knobs or joysticks should be clearly labeled with their function.  If electronics are used, all wires should be housed in a casing so they cannot be seen or accidently pulled. The color should be matched to the room so that it does not draw the attention of the patient.

**2. Production Characteristics:**

a. Quantity: there are two units. For the Cirrus unit, we need to be able to incorporate rotational movement. For the Stratus unit, we need to design a system capable of lateral, rotational and vertical movement.

b. Target Product Cost: we need to be as economical about materials as possible.

**3. Miscellaneous**

a. Standards and Specifications: none

b. Customer: would prefer to control any movements through a joystick.

c. Patient-related concerns: for animal studies, correct positioning of the chin platform is necessary to avoid injury to the animal

d. Competition: Although platform positioners and machine arms exist for moving heavy objects, they have not yet been applied for this purpose. The cost of such devices is extremely prohibitive, as well, based on a number of factors (precision, material used to build the structure, etc.)

BME 400 Research Project Purchase Order

Client: Carol Rasmussen

Financial Contact: Gary Leatherberry

Ophthalmic Camera Positioning Device

**Function**

The device must be designed to position the 80lb. Cirrus-OCT ocular imaging device currently in use by the Ophthalmology clinic. While the clinic's current positioning system is capable of crudely positioning the OCT camera in the vicinity of the eye, it lacks fine positioning capability. This device we design must be able to refine the position of the OCT device by distances as small as a few millimeters. It must be able to position the camera in the horizontal plane, tilt the camera, and rotate the camera. The user interface for such fine movements must be simple, accurate, and repeatable, as is the joystick positioning device used for a different model of OCT camera currently in use at the clinic.

**Allotted Budget: $1000**

**Expenses:**

Part Number 91236A803: Znc-Pltd Stl Low-Strength Hex Head Cap Screw 5/8"-11 Thread, 2-1/4" Length- 10 Pack, Quantity 1, $7.09

Part Number 91015A035: Case-Hardened Steel Extra-Wide Thin Hex Nut Black-Oxide Fnsh, 5/8"-11 Thrd Sz, 1-1/16" W, 23/64" H – 10 Pack, Quantity 1, $6.25

Part Number 91026A031: Case-Hardened Alloy Hex Thick (Heavy) Nut 3/8"-16 Thread Size, 11/16" W, 23/64" H, 10 Pack, Quantity 1, $5.34

Part Number 92865A761: Grade 5 Zinc-Plated Steel Hex Head Cap Screw 9/16"-12 Thread, 1-1/2" Long, Fully Threaded, 10 Pack, Quantity 1, $6.22

Part Number 95505A606: Grade 5 Plain Steel Hex Nut 9/16"-12 Thread Size, 7/8" Weight, 31/64" Height, 25 Pack Quantity 1, $4.20

Part Number 9017K16: Low-Carbon Steel 90 Degree Angle 3/16" Thick, 1-3/4" Leg Length, 6' Length, Quantity 1,

$31.86

BME 400 Research Project Purchase Order

Client: Carol Rasmussen

Financial Contact: Gary Leatherberry

Ophthalmic Camera Positioning Device

**Function**

The device must be designed to position the 80lb. Cirrus-OCT ocular imaging device currently in use by the Ophthalmology clinic. While the clinic's current positioning system is capable of crudely positioning the OCT camera in the vicinity of the eye, it lacks fine positioning capability. This device we design must be able to refine the position of the OCT device by distances as small as a few millimeters. It must be able to position the camera in the horizontal plane, tilt the camera, and rotate the camera. The user interface for such fine movements must be simple, accurate, and repeatable, as is the joystick positioning device used for a different model of OCT camera currently in use at the clinic.

**Allotted Budget: $1000**

**Expenses:**

| | | | | | |
|---|---|---|---|---|---|
| 1 | 1 Each | 5179A29 | Fine-Adjust Cross-Slide Table 18-5/8" X 6-3/16" Table Size, 5-3/16" Height<br>Please enter a quantity. | $244.38 Each | $244.38 |
| 2 | 4 Each | 6460K47 | Stud-Mount Ball Transfer Std, 1-1/4" Stl Ball, 3/8-16 X 11/16" Stud, 250#Cap | $11.51 Each | $46.04 |