Motion Stage for Optical Coherence Tomography

Submitted March 11, 2009

Client: Carol Rasmussen, Department of Veterinary Medicine

Advisor: Dr. Thomas Yen, Department of Biomedical Engineering

University of Wisconsin-Madison

Prepared by

Daniel Frost

William Stanford

Table of Contents

Content **Page**

Content	Page
Abstract/Background	3
Introduction	4
Specifications	5
Discussion of Alternative Designs	6
Final Design	7
Future Work	11
Ethical Concerns/Usability	12
Testing	13
Future Work	14
References	16

Daniel Frost[1], William Stanford[1], Carol Rasmussen[1]

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 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].

[1] Department of Ophthalmology and Visual Sciences, School of Veterinary Medicine, University of Wisconsin-Madison

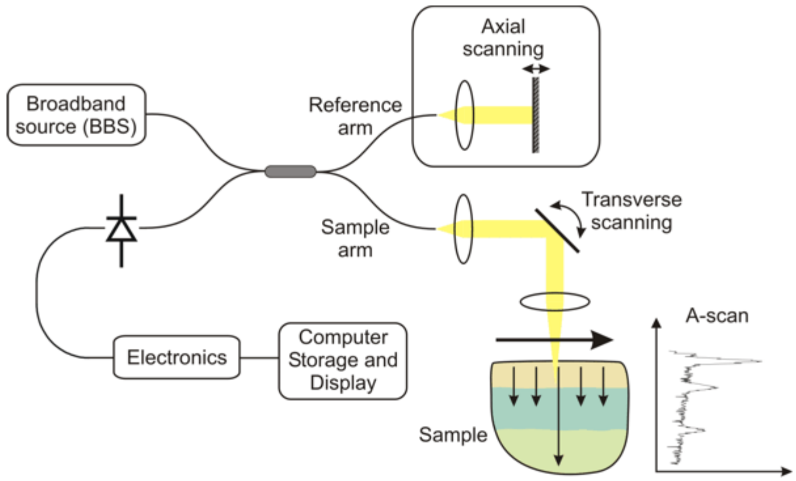

Figure 1: Schematic of Optical Coherence Tomography that demonstrates how important proper positioning of the laser system is.

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 controlled through the computer and requires the technician to concentrate on how the machine is moving while performing tasks on the computer

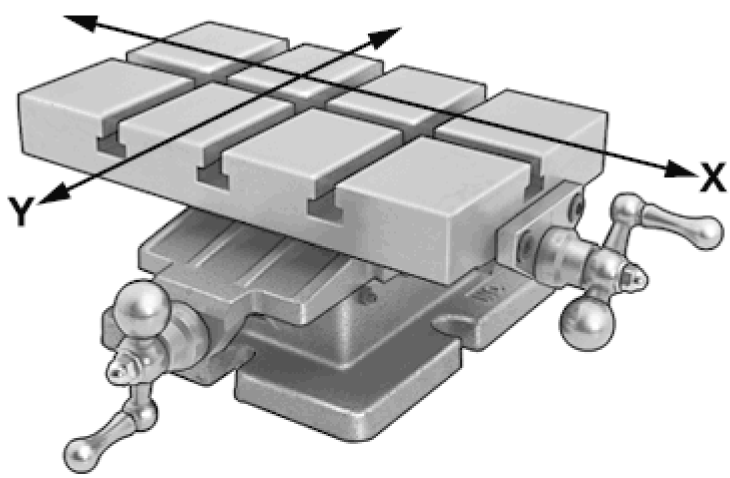

Figure 3: Fine-Adjust Cross-Slide Table, McMaster-Carr, http://www.mcmaster.com/

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 here 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 Figure4**.** 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

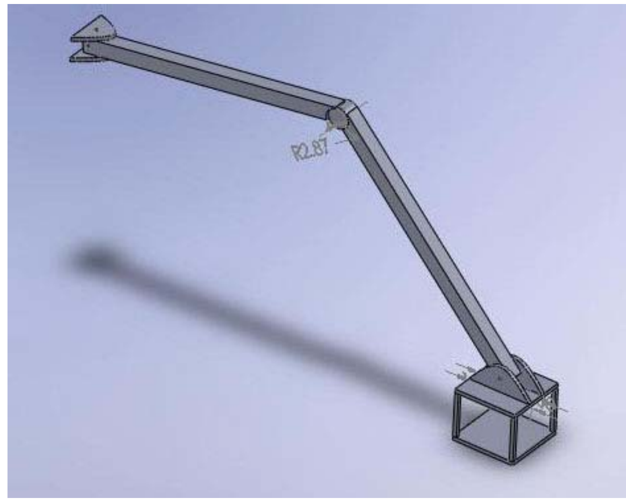

Figure 4: The precision slide with a screw bearing provides motion in one direction. The platform in the middle moves as the screw is turned by the knob on the right.

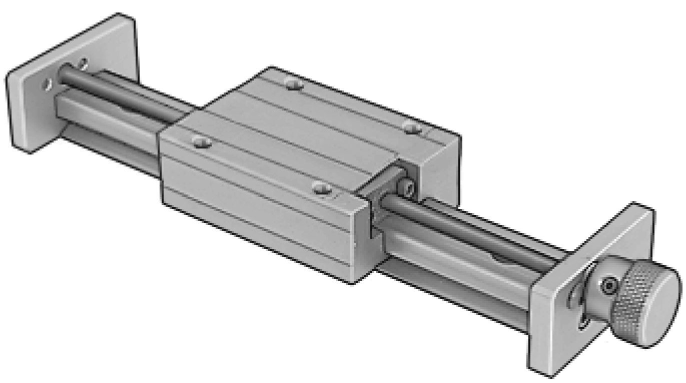

Figure 5: Overhead arm design consists of a cage to hold the camera and three joints to allow translational movement.

complete motion 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.

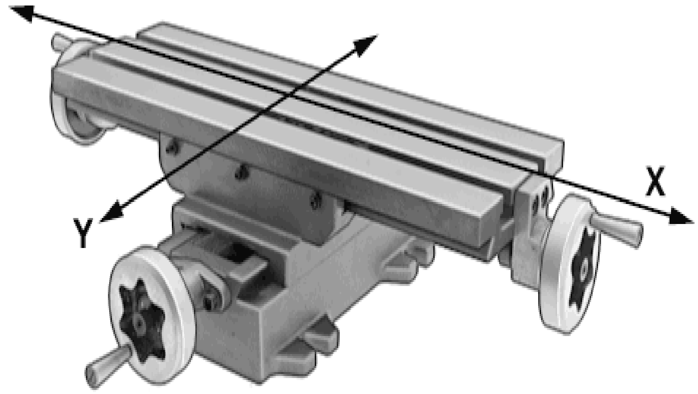

Figure 6: The motion stage device has two axes of rotation. They are shown in the picture as the x and y direction. The position of the stage is controlled by the three hand cranks.

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 0.001 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.

Discussion of Alternative Designs

Table 1: Design Matrix Detailing Critical Criteria in Design of Cross-Table

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.

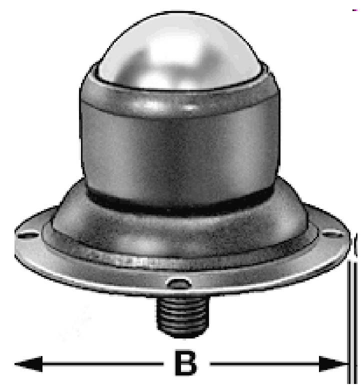

Figure 7: Ball Bearing, load capacity 250 lbs

In choosing the design, we weighed the number of degrees of motion and load capacity criteria with 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.

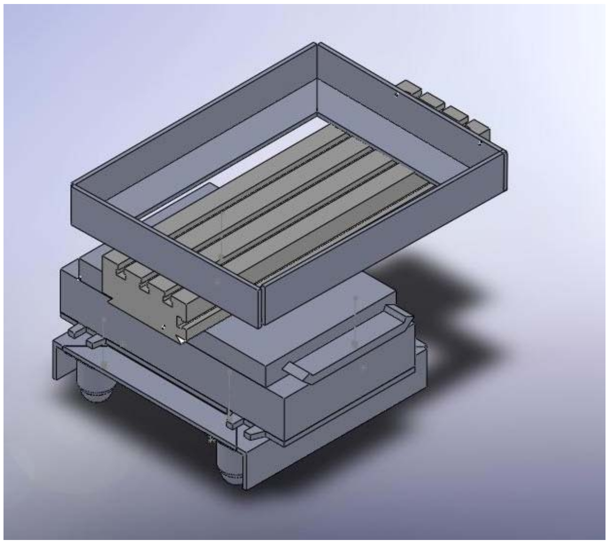

Figure 8: Solidworks Rendering of Final Design, ¾ view from side.

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.

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"** **Load capacity 150 lbs** **Table travel 12" X 8"** **Height 5 3/16"**
Bolts connecting frame to table	**5/8"**

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.

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.

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.

Testing

An important component of this semester is testing the device to ensure it provides a significant improvement over the current design. According to the client, the current system takes approximately fifteen minutes to align the device correctly with the subject's eye. She states that the process should take no more than two minutes. This is about how long it takes to align the device with a fully coherent patient and the cameras aligning chin rest. To test the device, a model target will be needed. Our client may be able to provide a model eye that will provide an aligning target. Otherwise, a small dot on the wall will work. A laser will be attached to the camera just above the lens to act as an aligning measurement device. The camera and table will be moved to different starting positions and then moved in order to align the laser with the target (Figure 9). This will be done with both manual control and electronic control. The amount of time and distance traveled for each alignment will be recorded and averaged. It will be necessary to do some statistical tests to see if there is a significant difference between alignment times for the manual control and the electronic control.

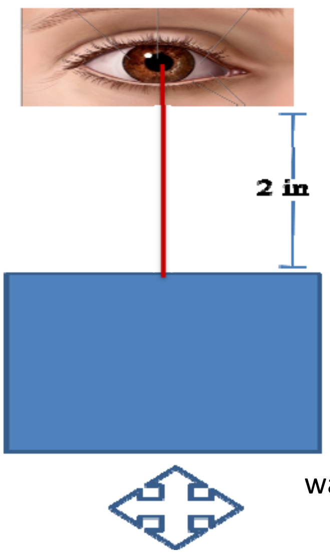

Figure 9: Diagram of test. The blue box represents the camera

Future Work

The goals for the rest of this semester to finalize our design deal with making the device as easy and efficient as possible for the user. The first upgrade that we will pursue will be to fit the cross-slide table with the 1075 RPM motors we have purchased. To start, two motors will be used, and each will move the table horizontally, one parallel to the patient and one perpendicular. Next, we will use a third motor with a worm drive and a wheel positioned beneath the table for rotation. When the motor turns in a certain direction, it will cause the wheel to also turn, and this will move the table in an arc about a point directly in front of the imaging lens. The worm drive will be effective in stopping the rotation at the exact desired point; without a worm drive it is hard to make the table stay at a precise angle. Along with each motor we will attach a motor controller, and these will be important in ensuring that the timely operation of the device. The controllers will allow the motors to be turned at varying speeds, depending on how much voltage is put in.

Figure 10: Motor that will be used to move the device horizontally and for rotation.

When all of the motors are working properly, we will connect them to a three-axis joystick, which will be purchased when the operation of the motors is adequate. Using the motor controllers, this joystick will be able to control the speed of the

Figure 11: Joystick that will control all three degrees of motion.

motors, and in turn the movement of the table, based on how far the stick is pushed in a certain direction. This ensures that the operator can make large adjustments quickly, and still be able to finely tune the position of the imaging device.

The final step in improving the efficiency of the design will be in improving its safety aspects. The motors and worm drive will improve the stability of the table will not in motion; however, moving the table past certain points is undesirable. If the table moves in excess in a horizontal direction, the weight of the imaging device could create large moments about the center point of the table and tipping may result. As for rotation, the table should not need to move more than 30 degrees in an arc around the pivot point. To account for these potential hazards, we will be installing stopping mechanisms for all of the motors, which will shut the motor off if a critical point is reached. This will ensure that there are no accidental problems resulting from excess motion. These three improvements will make the design safe and easy to operate.

References

[1] Clin Experiment Ophthalmol. 2008 Sep 23. [Epub ahead of print] Links
Ophthalmic imaging today: an ophthalmic photographer's viewpoint - a review.

[2]The Evolution of Spectral Domain OCT. (2008, July). Retrieved Nov 30, 2008, from Optometric Management:
http://www.optometric.com/archive%5C2008%5CJuly%5CSupplements%5COM_DIBG%5Cimages/O
M_July_DIBG_Suppl_A03_Fig07.jpg

[3]McMaster-Carr. (2008). Cross-Slide Tables & Turntables. Retrieved 30 Nov, 2008, from http://www.mcmaster.com/catalog/114/gfx/large/5179a29c1l.gif