Miniature Robotic Arm to Manipulate Ophthalmic Lenses

Kassim Kaba, Faris Baksh, Yazeed Almashan, Bader Alsubaei, Austin Bach[1], Melissa Morris, Sabri Tosunoglu

Department of Mechanical and Materials Engineering
Florida International University
Miami, Florida

[1] TYB, Inc.
Miami Beach, Florida

kkaba001@fiu.edu, yalma011@fiu.edu, fbaks003@fiu.edu, balsu004@fiu.edu,
austinbach@gmail.com, mmorr009@fiu.edu, tosun@fiu.edu

ABSTRACT

In this project, a small robotic device intended to replace the human arm during certain eye examinations and procedures was developed. Specifically, it is an attempt to remove tremor and fatigue in the arm of ophthalmologist who traditionally performs these operations manually as well as allow remote control of the lens position. This miniature robot provides physicians with a cost effective and user friendly option that increases precision, accuracy and ergonomics, while reducing risk and fatigue. This paper illustrates how this project achieved these goals. It builds upon previous work done by three of the authors.

Keywords

Robotic Arm, Ophthalmology, Examination

1. INTRODUCTION

1.1 Problem Statement

There exist more than one hundred different types of surgeries in medicine and none of them are hundred percent risk free. This means that there is plenty of room for improvement to make operations safer. Certain ophthalmic (eye) surgeries have a noteworthy amount of risk. Due to the inherent human tendency for both the physician operating the equipment and patient attempting to remain still to become fatigued over time, the longer a surgical procedure takes, the riskier it becomes. The sensitive and delicate nature of the eye increases this risk. Currently, many ophthalmologists perform eye exams on patients using a machine called a slit-lamp. Mounted on the patient side of the slit-lamp is a chin rest to allow positioning and stability of the patient's head during the examination. To examine many interior structures of the eye such the retina, the physician is forced to hold an additional lens on the eye of the patient on the other end of the slit-lamp from their position. These lenses are also held in place this way for many laser surgery procedures done with the slit-lamp. It therefore requires the physician to remain in an awkward position to hold the lens steady or make small adjustments for long periods of time. This causes fatigue in the arm of the doctor, which increases instability and therefore the risk for a laser to hit the incorrect target and possibly damage the eye. The robotic device proposed and implemented in this paper, named the Miniature Robotic Arm (MRA), can eliminate fatigue and thus get closer to a fully safe ophthalmic surgery.

1.2 Motivation

Engineers build tools, devices and machines for many reasons such as improving performance, efficiency and more. The project presented here is no different. MRA was intended to reduce the risk of laser eye surgeries, particularly retinal procedures. In doing so, this lens holding robotic arm also can increase the productivity of the physician, the accuracy and reliability of the laser targeting, as well as both the safety and comfort of the patient. Additionally, it helps move innovation one step closer to remotely performing eye examinations and surgery. Ultimately, this is an opportunity to help make people's lives better because it is needed by ophthalmologists and by extension the medical field.

1.3 Literature Survey

Many technological advancements have been made in the field of ophthalmology in recent decades. In 2010, the BQ 900 LED was introduced as the first LED slit-lamp in the world. Despite all the advancements made to slit-lamps in over a century since they were introduced, physicians still physically hold external lenses on the patient's eye to view certain optic structures. There does exist steady rests to hold a lens to an eye, but this rest must be manually moved should the physician want to change the lens position to see some other part of the eye or if the patient moves.

Introduced in 1999, the Da Vinci system remains the standard robotic surgery system for cardiac, colorectal, gynecologic, thoracic, urologic, head, and neck surgeries [1]. The U.S. Food & Drug Administration (FDA) continues to approve its use in an increasing range of surgical applications and some are investigated its use in ophthalmic procedures. Along with the Da Vinci robot, there are hundreds smaller robotic devices that help with tasks that require great precision such as the Mako orthopedic surgical system and the Mazor spinal surgery positioning system. These systems help to illustrate the increasing usefulness and acceptance of specialized surgical robotic systems. Robotic surgery had advantages and disadvantages over traditional manual surgery as outlined in Table 1 below.

Table 1. Advantages and disadvantages of robotic surgery

Advantages	Disadvantages
Precision, accuracy, stability	Poor decision making/judgement
Amplified scale of motion	Poor interpretation of qualitative data
Reduced tremor	Expense and maintenance
Multitasking	Availability
Automation	Learning curve
Association of imaging systems	Possibility of malfunction
Teleoperation	Patient trust

Reflecting on previous innovations in robot assisted ophthalmic surgery, it can be seen that the robots were designed and built for either single specific tasks or assisting in technically difficult portions of procedures [2]. In the 1980's the Stereotaxical Micro-telemanipulator for Ocular Surgery (SMOS) was invented in France. As one of the first micromanipulators, it allowed four degrees of freedom (DOF). Years later, investigators at Johns Hopkins University developed a steady hand manipulator (SHM) for retinal microsurgery. This device consists of an arm with tilt and roll mechanisms that allowed the instrument to move along with the surgeon [3]. In 2007, an advanced and optimized version of a new SHM for retinal surgery was designed and fabricated. This extended earlier work on cooperative manipulation in microsurgery and focused on performance augmentation [3].

The first robotic ophthalmic surgical device to go to market is expected to be the Preceyes system [4]. This device is intended for performing procedures that require instruments to enter the eye.

A robot intended for both ophthalmic examinations as well as non-invasive laser procedures is under development [5]. This paper describes work that is continues the development of one component of that device, the remotely operated lens holder.

2. PROTOTYPE CONSTRUCTION

This section describes the design, analysis and construction of the Miniature Robotic Arm prototype. overall building process is discussed.

2.1 Description of the Prototype

The MRA prototype can be divided into three major sections. The first section consists of the support, which is the foundation that supports the whole device as its name indicates. It consists of a base structure affixed to the slit-lamp table to which is attached two perpendicular aluminum rods. These rods allow for gross adjustment in height and length to accommodate various patient physiology. In the preliminary design shown below in Figure 1, inner rods are connected to eachother and fixed to outer rods through adjustable handlebars that are tightened and released to obtain the desired position.

Figure 1. Adjustable cylindrical bars for vertical and horizontal motion

The second major part of the MRA prototype is the track. This component is connected to the end of the inner horizontal rod of the support. It forms a straight perpendicular track with respect to the horizontal bar allowing gross adjustment closer or further from the eye.. The track is made of two small I-beams to which a flat plate is attached to and thus enables a sliding motion back and forth.

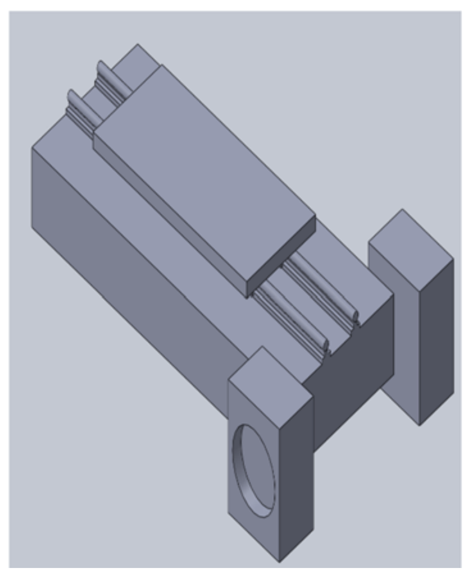

Figure 2. Lens holder base

The third major component of the prototype is the lens holder. The preliminary design is shown in Figure 3. This is the piece having the highest degrees of freedom is the most important part of the system. Inside the lens holder outer bezel, there is an inner bezel held within a track. The inner bezel has screws that can be adjusted to hold any size lens. It also includes a gear to facilitate asymmetric lenses to be rotated parallel to the patient's face when a geared pinion is mounted to a motor to actuate this motion. The outer bezel is mounted by two pins to a bracket. The bezel can rotate about the pins via an actuator to adjust the angle about the horizontal axis in front of the patient's eye. The bracket is able to rotate about the vertical axis in front of the patient's eye via a swiveling base controlled by a third actuator. The lens holder assembly is fixed to the track portion noted above.

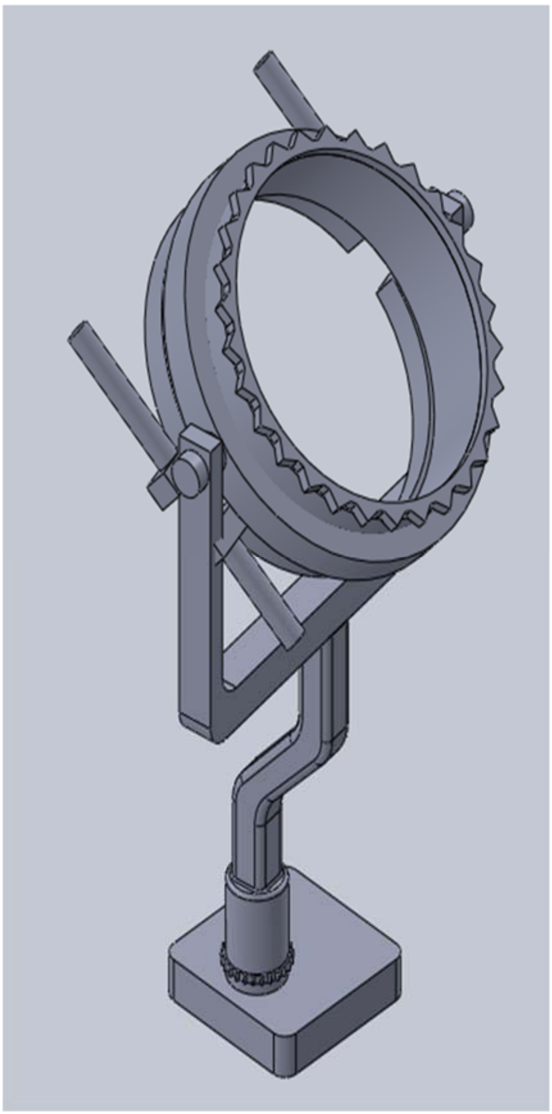

Figure 3. Proposed lens holder design

2.2 Prototype Design

The complete design with all three parts mentioned above was rendered in SolidWorks. The system model was modified to determine how the physical parts would fit until a final design, shown in Figures 4 and 5, was produced. Analyses were performed to verify that the design was suitable to hold the lens stable. Appropriate actuators were identified to control the actuated components.

Figure 4. Front view of assembly of components

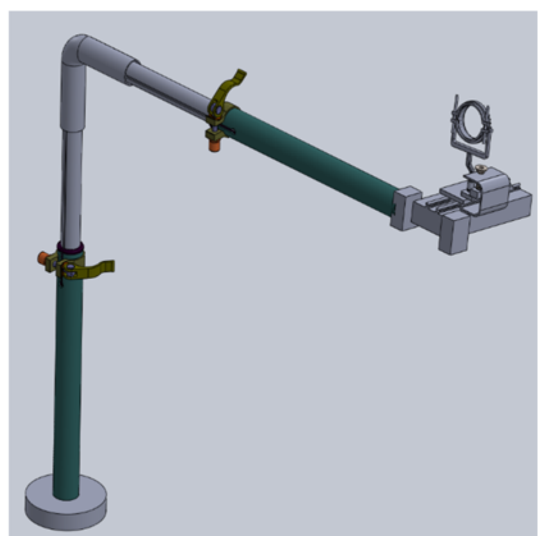

Figure 5. Isometric view of full assembly

2.3 Parts List

The parts involved in the construction of this project are a combination of different types of materials including: PLA, wood aluminum and other metal.

The parts list includes:

2 aluminum bars

3 small pieces of oak project board

10 screws

3 servo motors

2 small pieces of thick metal wire

Brace corner

Hex nut and hex bolt

Arduino R3 (interchangeably used with Raspberry Pi 3)

Ethernet Shield (for interface use via router or Wi-Fi)

2.4 Construction

As expected a project of this complexity required a large amount of trial and error in order to have all the parts come together as one. The building process was performed in two main steps. The first was assembling all of the necessary parts to build the lens holder. The second step was attaching the lens holder to the base support and track to make it a function as one complete usable device. The prototype has been altered many times before having a functional MRA shown.

Many of the lens holder parts were 3D printed. Photos of this process are shown in Figures 6 and 7. The outer bezel was printed in two pieces and glued together so that the inner bezel was secured within a track. The rotational movement was attempted via a servo mounted to the outer bezel with a pinion engaging the geared ring of the inner bezel.

The rotational motion about the pins connecting the bezel to the bracket was achieved by mounting a servo to the bracket and using two thick wires to form linkages from the two arms of a long symmetric servo horn to the ends of two bars designed on the bezel for this purpose.

The vertical rotation was achieved simply by mounting the bracket to a servo horn and mounting the servo base to the base track. The final lens holder portion is shown in Figure 8.

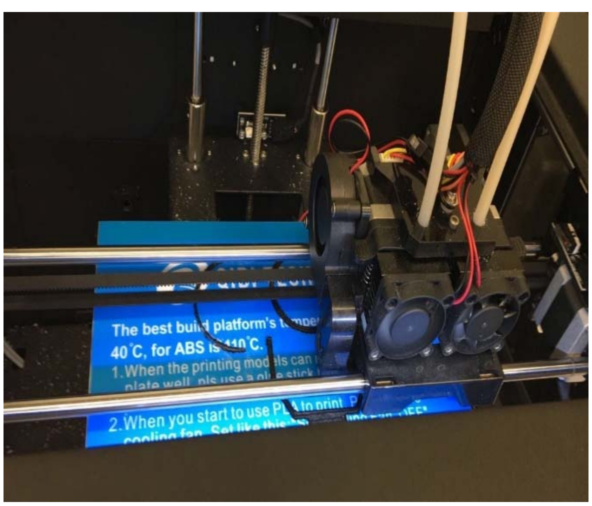

Figure 6. 3D printing of lens holder parts in progress

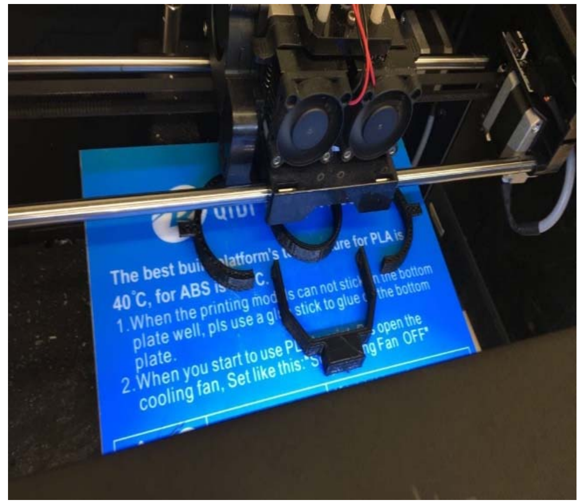

Figure 7. 3D printing of lens holder parts completed

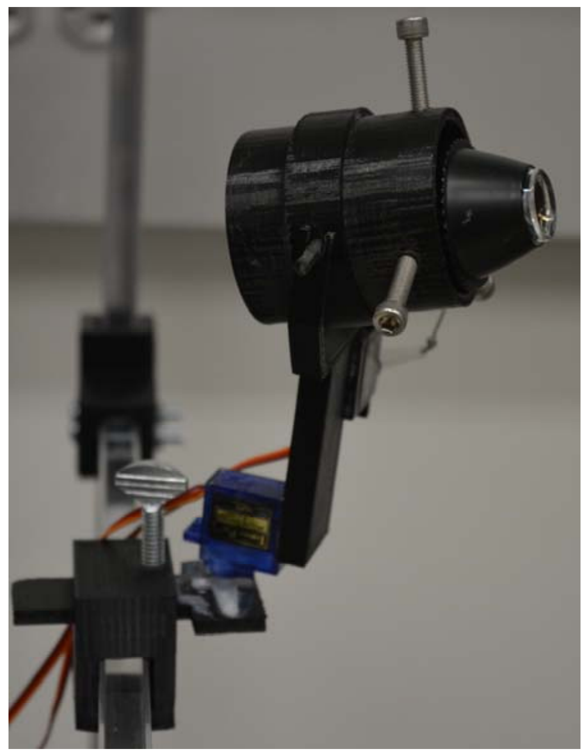

Figure 8. Completed lens holder portion of the MRA

The track portion of the base was also 3D printed. It was assembled by slipping the two parts together.

The base support system was originally constructed in a manner similar to that shown in Figure 1. In order to utilize quick-release levers, bicycle frame was used. The completed base proved to be very stable, but was much too large to comfortably use in front of the patient's face and to fit well between the slit-lamp and chin rest. A second iteration involved redesigning the base and using smaller square hollow extruded aluminum bars. Adjustments to height and length were facilitated by the manufacture of brackets that fit over the bars and are secured to the desired position by tightening thumb screws. The complete assembly is shown in Figure 9 below.

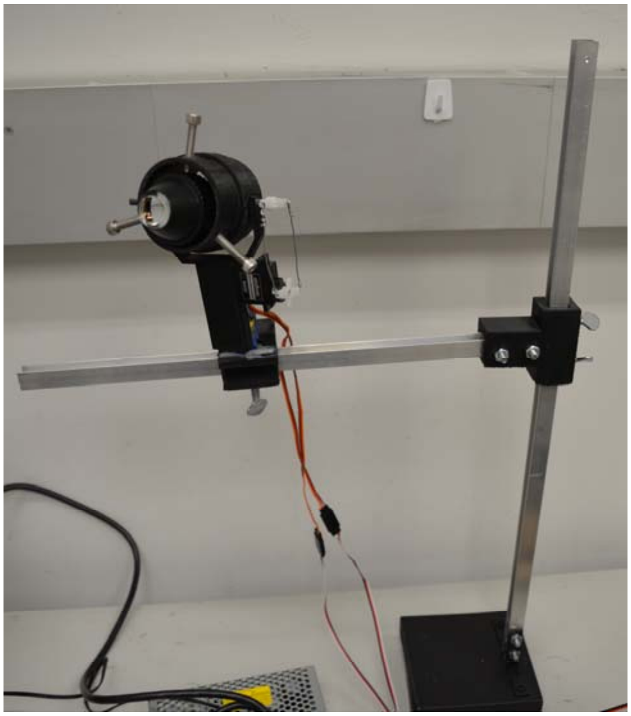

Figure 9. Complete MRA prototype with lens in place

3. TESTING AND EVALUATION

As mentioned in section 2, the objective of this project was to create a device that could replace the arm of a physician and allow holding and remote manipulation the lens for long period of times during ophthalmic examinations and laser procedures. By doing so, this would eliminate arm fatigue and tremor while increasing precision and accuracy. To verify the functionality of the prototype, an experiment was done to illustrate through data the improvement that the Miniature Robotic Arm brings.

3.1 Design of the Experiments

The objective of the experiment is to find the difference between a human physically holding a lens weighing less than 5 ounces versus the developed device holding it in place.

The procedure is as follows:

- Assemble on a table a stopwatch and a small lens weighing between 3–5 ounces.

- Using an individuals between the ages of 20-30, record how long each person can hold the lens vertically while keeping his elbow at a 90° angle before feeling any sort of discomfort.

- Record the time that the discomfort started to the point when the person can no longer keep their arm up due to pain and/or tremor.

- Show test result and data in graph and/or table.

- Discuss and evaluate the experimental results.

For this experiment, some assumptions were made. It was assumed that the stress caused by the 3-5 ounces lens on the aluminum bar would be negligible for the maximum time span of this experiment of two hours.

3.2 Test Results and Data

Using the participation of healthy male of the ages of 22, 23, 25 and 27 respectively, the graph below in Figure 10 represents that discomfort rapidly increased over a three minute period. The graph shown in Figure 11 illustrates what is virtually a negligible stress applied to the lens holder over the same period of time as derived from modeling.

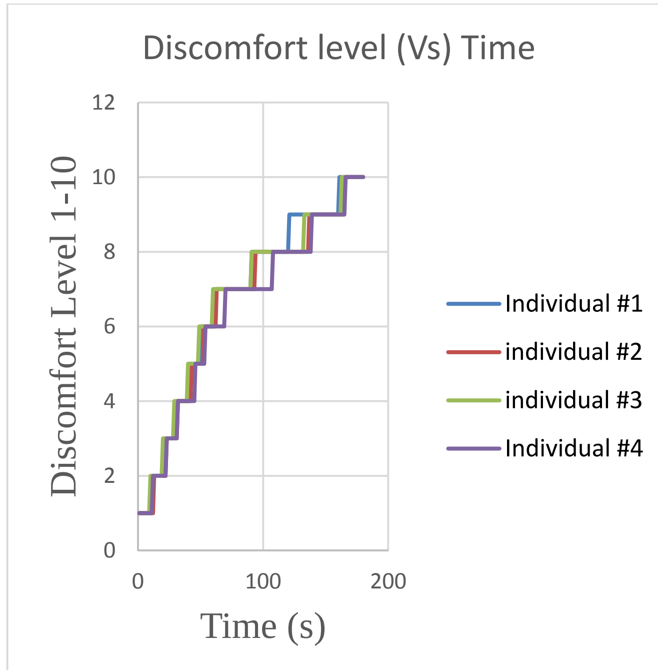

Figure 10. Human discomfort level vs. time

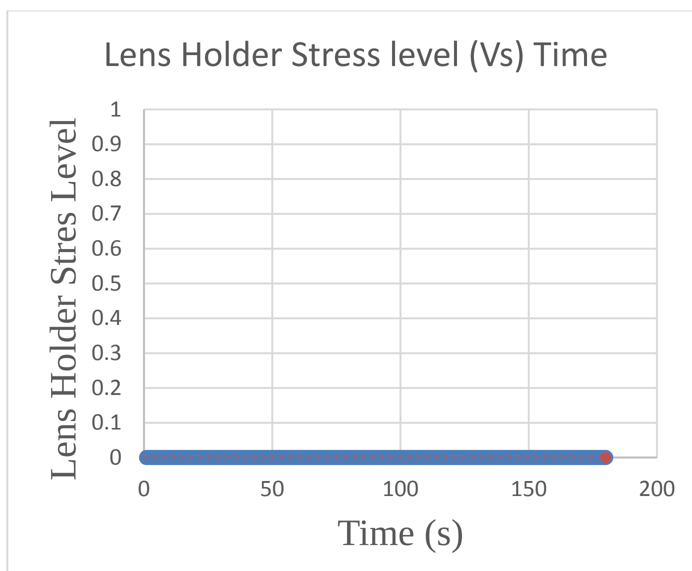

Figure 11. Lens holder stress level vs. time

3.3 Evaluation of Experimental Results

It is intuitively obvious that a human arm would get fatigued much more quickly than a physical object which is designed to stand in place holding the specified weight steady. However, the graph helps to visualize how much difference the robot can make even over a short period of time. It is important to note that even thought this experiment was performed by young adults, typically an ophthalmologist will spend their career while in their early 30's to late 60's [5]. In other words, if young healthy men holding a lens feel a considerable discomfort after only three minutes in one position, it is fair to conclude that older men will most likely feel unease sooner. Thus, the value of the lens holder is enormous to the ergonomics of ophthalmologists around the world.

3.4 Future Work

A few improvements can be made to the design following the experiment. First, the lens holder must be strong enough to hold the heaviest lenses without allowing any instability. Second, the device must be durable enough that it can be used multiple times every day and for long periods of time during each use.

It is also suggested that in future implementations, a strong yet light actuator be used to allow for the rotation of the lens. The SG90 servos that were sufficient for the two other motions did not provide enough torque to rotate the inner bezel. This was due to excess and uneven friction caused from rough surfaces created from the 3D printing process. Close up photos of the final prototype are shown in Figures 12 and 13.

Figure 12. Final prototype lens holder

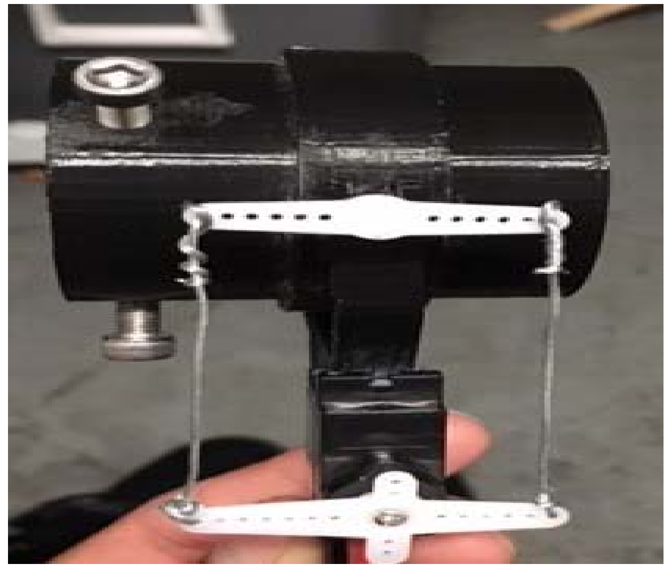

Figure 13. Side view of final prototype

Finally, it is feasible that in the next iteration, the gross adjustments will be actuated to allow for remote adjustment. This was not a goal of the prototype as someone will be able to manually insert a lens and adjust the general position of the lens according to the position of the patient. Actuation could be helpful, however, as it would allow for quick adjustment whether remotely or in-person. Quick adjustments may provide relief for the patient attempting to remain still for long periods of time or allow for the physician to remotely position a patient to more conveniently obtain a view of an area of interest.

4. CONCLUSION

Testing and evaluation allows engineers to validate their intuition, expectations, and purpose. It is also an opportunity, for a project to differentiate itself from others by providing solid data and results to back out the product. For this project, the data reveals how useful this machine can be for the productivity of ophthalmologist as well as the safety of patients. Additionally, this was an opportunity to improve a previous design and obtain a better solution as determined from the conclusions drawn from the experiment. The lens holder was integrated into the slit-lamp system developed and the robotic portion was successfully remotely actuated through the web interface.

5. ACKNOWLEDGMENTS

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