iPhone Virtual Reality Training Model for Microsurgical Practice

BME 301
University of Wisconsin-Madison
Department of Biomedical Engineering
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Abstract

Microsurgery training is generally very expensive and students do not always have access to a hospital where the necessary equipment is available. The team has been tasked with creating a microsurgery training tool that is compatible with a smartphone in order to reduce the cost of training as well as make it possible to train from any location. The video from the smartphone must also be accessible in a live format so instructors can view the training process and give feedback in real time. Also, the device should be able to reproduce stereoscopic vision in order to replicate the depth perception possible when using the optical microscope in the operating room. The team has created three possible designs, and has decided to pursue a single phone camera based design which utilizes mirrors to achieve two different viewing angles on the subject using grey pro resin for the housing of the mirrors. These two different viewing angles, when output through a VR headset, will allow the user to have a clear view with depth perception of the operating environment. The team will produce a prototype of this design and test it, comparing it to the effectiveness of the traditionally-used microscope for microsurgical practice.

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1. Introduction

1.1 Motivation

There is an ever-growing need for microsurgeons, but resources available for training tend to be hard to access and expensive. It can be difficult, costly in time, and expensive to travel to a medical center where these resources are available. Especially during the COVID-19 pandemic, it has been proven that virtual training is advantageous and preferred for medical students [1].

1.2 Problem statement

The team has been tasked with making it easier for microsurgery students to practice by designing a training tool that uses a smartphone lens, is capable of creating depth perception, and has a high quality resolution comparable to a surgical microscope.

2. Background

2.1 Surgical Microscopes

Surgical microscopes provide a view of the surgical site that has both depth and high resolution. They obtain this stereoscopic image through a series of prisms and lenses to enlarge the image while maintaining the quality [2]. These microscopes, however, are very expensive and can range anywhere from $200,000 to $1 million [3]. This project compares to a surgical microscope at Wisconsin Institutes for Medical Research that is approximately $300,000. Alternatively, the iPhone 13 base price ranges from $800 to $1,000 depending on how much storage it has [4]. Although the resolution and zoom are not as high in quality as that of the generally-used microscopes, it is comparable enough to be used for training purposes.

2.2 Smartphone Cameras

Smartphones are widely accessible and provide flexibility for a trainee to practice anywhere they would like and therefore aren't restricted only to the location and time availability of surgical microscopes. The issue iPhones present is that they lack the depth perception that microscopes provide.

2.3 Stereoscopic Display Technology

There are many options available for viewing stereoscopic images such as 3D glasses or VR headsets. Auto-stereoscopic displays are displays that allow for 3D depth perception without the need to wear a headset or glasses. A viable option for creating an auto-stereoscopic display would be to use a parallax barrier. A laptop screen can display the 2 different angles of the same subject interlaced between every other pixel. The parallax barrier works by blocking the left image from reaching the right eye and vice versa[5].

2.4 Clients

The team's clients are Dr. Ellen Shaffrey and Dr. Samuel Poore. They are both plastic surgeons at the UW Hospital in Madison, Wisconsin. They are looking for a way to affordably train many microsurgery students in a way that is similar to using a real microscope.

2.5 Previous Work

2.5.1 Previous BME Team and Clients

The clients previously used a Google Cardboard, an iPhone to record, an iPhone in the headset, and a laptop to transfer the 3D image. This achieved depth but lowered the accessibility and increased delay time. The previous BME team decided to combat this by developing a program that would create the 3D image internally, in order to reduce the delay between devices. However this program was slow to process, creating internal lag time.

Figure 1. Client's Google Cardboard design to increase depth and accessibility. Photo provided by clients.

2.5.2 Work From Previous Semester

Last semester, the team designed a prototype that sends two images to the smartphone sensor to allow for stereoscopic vision. The design, as seen in figure 2 consists of a cardboard housing with a series of inner and outer mirrors that allows for the two different views of the subject to be sent to the sensor. This design was then tested by streaming the video from the sensor to another smartphone in a Google Cardboard headset, which can be seen in figure 3. A ray diagram representing the device can be referenced in figure 4**.**

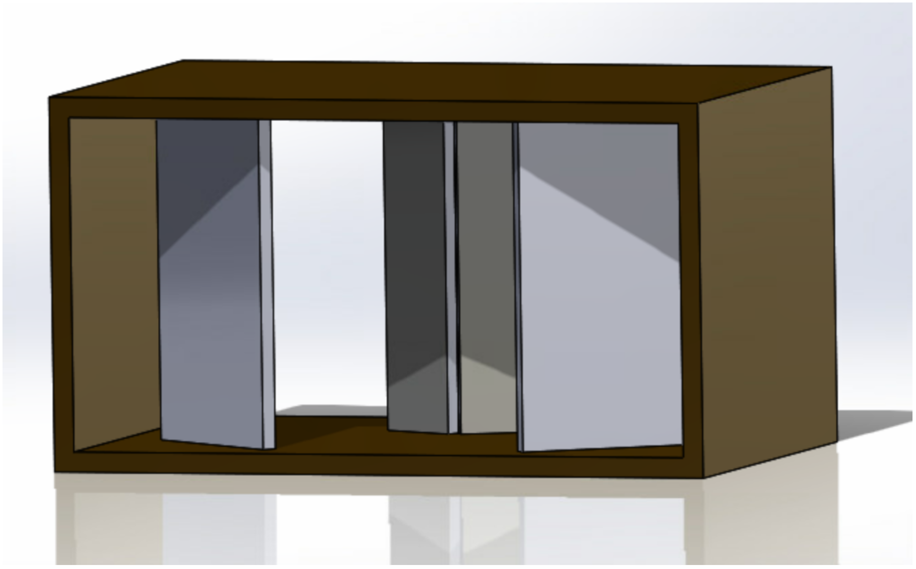

Figure 2: *CAD drawing of the previous semester's design.*

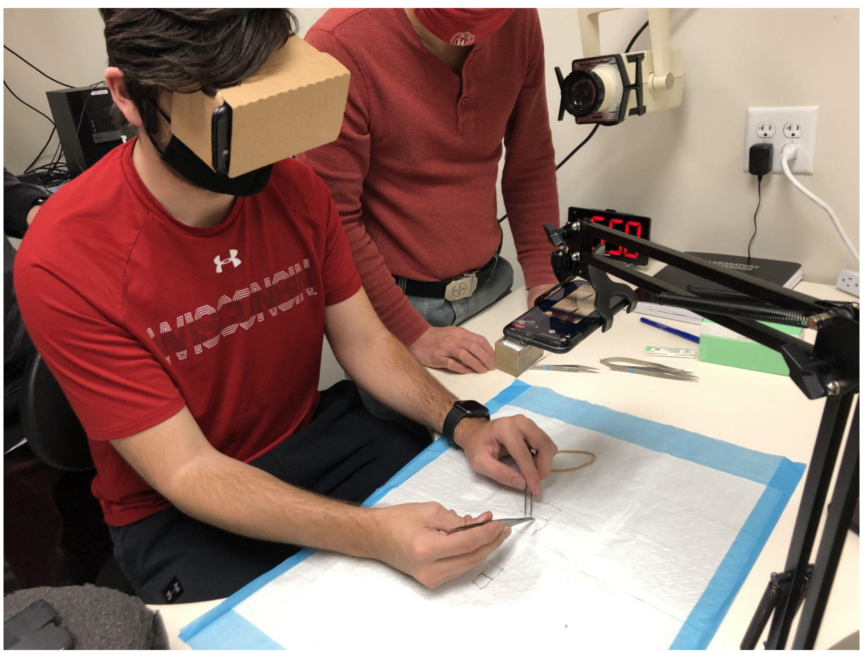

Figure 3: *Testing the device using the Google Cardboard headset. The device can be seen attached to the smartphone that is mounted on the boom arm.*

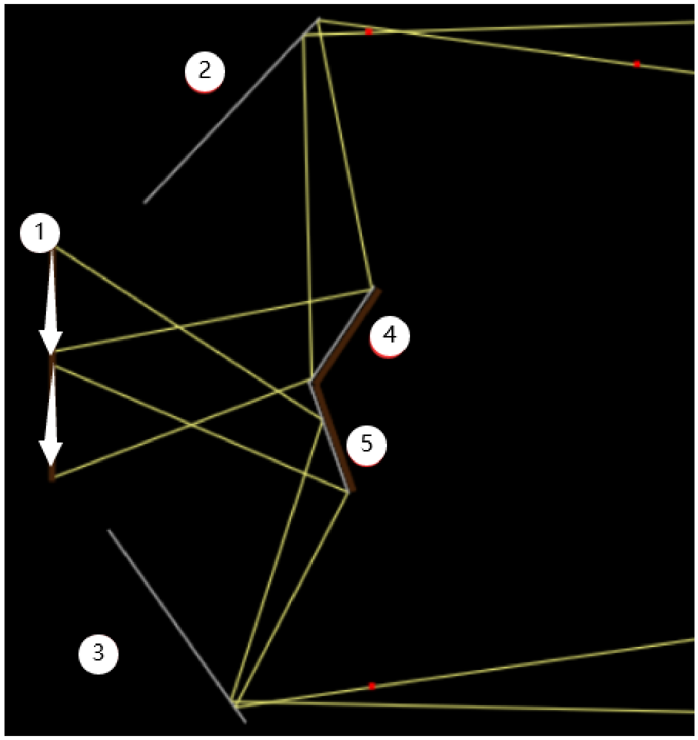

Figure 4: *Optic simulation. Light from the subject gets reflected by the outer mirrors (2), (3) onto the inner mirrors (4), (5). Then, light will be directed through the camera lens (1), forming two identical views of the subject. (represented by two upside-down arrows). Arrows will be converted upright by the camera lens.*

The device was able to send two different images of the same subject to the smartphone sensor, but when viewed through the VR headset the images did not combine well enough to create the needed depth of field effect. This was caused by the mirrors being unstable in the cardboard housing. This design allowed the team to modify the device very quickly, but it also lacked stability. Therefore, this semester will be focused on creating a more rigid housing for the mirrors that will output a consistent image with every use. Also, software will be used to better align the two images for viewing in the VR headset.

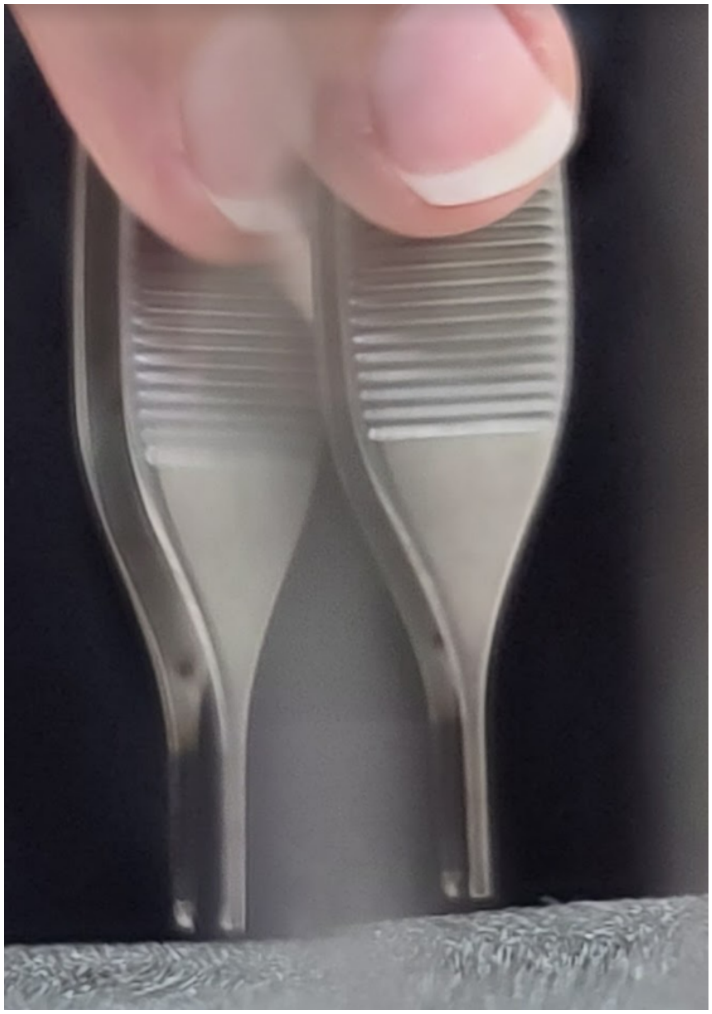

Figure 5: *A pair of forceps as viewed through the device.*

2.6 Product Design Specifications

The clients specified that the final product should allow for depth perception in regard to where the trainee's hands are in the work space. Additionally the zoom capacity and resolution needs to be high enough to clearly see sutures that are 0.070 mm in diameter. It must be inexpensive and widely accessible. Finally it should have a streaming resolution of 10.2 megapixels and stream delay of no more than 0.5 seconds. To allow for max functionality this design will be mounted on an adjustable stand and be of a low weight of less than 4.5 kilograms as to not interfere with worksite.

2.7 Competing Designs

The team's design will try to emulate the experience of performing surgery through professional microscopes used in the surgery room but at a fraction of the cost. Two surgical microscopes that are currently used for microsurgeries are the Mitaka MM51 microscope and the Orbeye 4K 3D Orbital Camera System. The MM51 is an optical microscope that requires the surgeon to look through two eyepieces [6]. Because the microscope is restricted to a top down perspective, the surgeon doesn't have as many possible viewing angles. Also, looking into the microscope restricts the surgeon's field of view. The Orbeye Camera System solves this issue by using a 4K camera mounted on an arm that transmits the video to a 3D stereoscopic display [7]. This allows for many different viewing angles as well as a more ergonomic seating position for the surgeon.

3. Preliminary Designs

3.1 Grey Pro Resin

Figure 6: *Example of 3D printed material, Grey Pro Resin from Formlabs[8]*

The first material option for the housing of the device is the Grey Pro Resin from Formlabs. This material is available for being 3D printed at the UW Madison Makerspace. The Grey Pro Resin has a precision of 50 micrometers. It also offers a tensile modulus of 2.6GPa [8]. This strength is needed to ensure the lens does not move when in use. This material is also very inexpensive being only $0.26/mL especially since the attachment that will be printed is only 2.5x2.5x5cm. [9]. The Grey Pro Resin is pretty lightweight with a density of 1.08g/cm^3 which is essential to the design as it will be used as an attachment to the iphone[10]. A dense material could make the device difficult to use. This option is also intended for repeated use and handling and aesthetic[8]. This is ideal for the product as the attachment is intended to be used for students to practice microsurgery.

3.2 Tough 1500 Resin

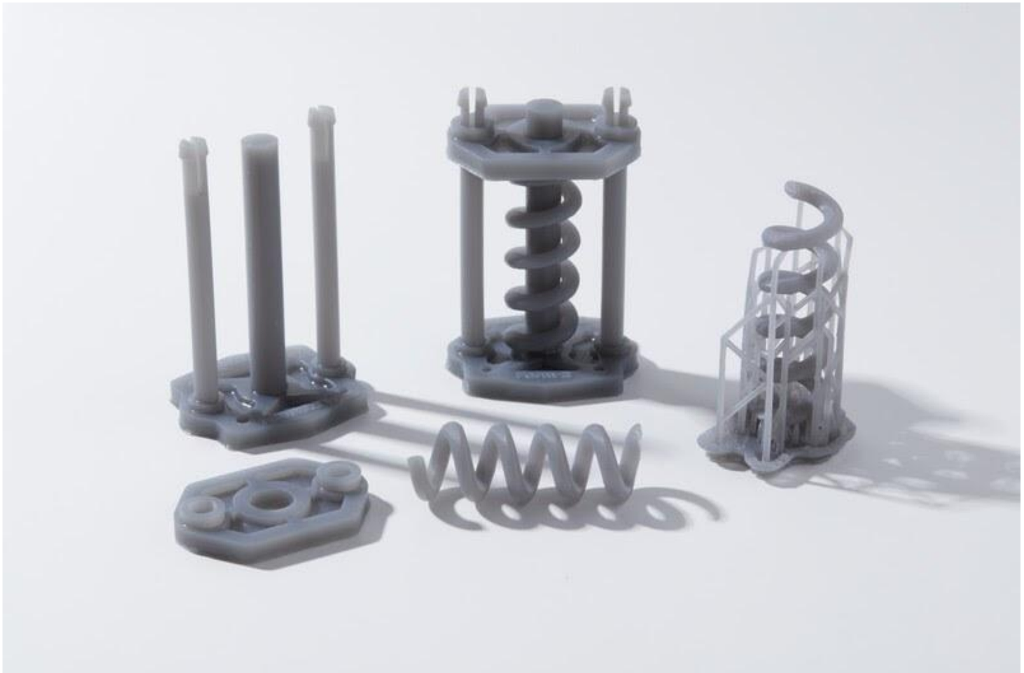

Figure 7: *Example of 3D printed material, Tough 1500 Resin from Formlabs[10]*

The second option for materials in the final design is also available for 3D printing at the UW Madison Makerspace. It is called the Tough 1500 Resin. This material offers the same precision as the Grey Pro Resin with 50 micrometers. However, this option has a lower tensile modulus of 1.5GPa. The Tough 1500 resin is then a pliable material and is not recommended for fine features[10]. Although Tough 1500 is not an ideal replacement to Grey Pro, the most optimal replacement being Tough 2000 with better mechanical strength, it is currently available at UW Madison Makerspace unlike the Tough 2000. This material has a similar density to the Grey Pro Resin with 1.07g/cm^3 [11]. It also has the same cost as the Grey Pro Resin.[9]

3.3 Laser Cut Acrylic

The last option is acrylic. In this option a laser cutter would be used on a sheet of acrylic into pieces that would be attached together to create the housing of the product. The laser cutter involved is the universal laser systems ILS95.150D that is available at the UW Madison Makerspace. This option gives more precision with 10.5 micrometers as this uses a laser cutter and the other materials use a 3D printer. [12] The acrylic is more expensive than the previous materials being $10.75 for a 18x25x1/8 inch sheet [13]. This material is slightly more dense than the previous options being 1.19g/cm^3. [14] The acrylic does have the largest tensile modulus with 2.8GPa which again is important to prevent the movement of the lens causing errors in the microsurgery training. [15] The biggest problem that arises with this option is that the pieces of acrylic would have to be manually attached together which gives the possibility of human error. This could alter the lens placement and in turn affect the accuracy of the training.

4. Preliminary Design Evaluation

4.1 Design Matrix

Criteria		Grey Pro Resin (Foamlab)		Tough 1500 Resin (Foamlab)		Acrylic (Laser Cut)	
	Weight	Raw Score	Score	Raw Score	Score	Raw Score	Score
Quality (Precision)	30	4/5	24	4/5	24	1/5	6
Durability (Strength)	25	5/5	25	3/5	15	5/5	25
Ease of Fabrication	20	3/5	12	3/5	12	5/5	20
Cost	15	4/5	12	4/5	12	2/5	6
Stability	5	5/5	5	5/5	5	1/5	1
Safety	5	4/5	4	4/5	4	5/5	5
Total	100	25/30	82	23/30	72	19/30	63

Table 1: *Design matrix of proposed materials. The criteria assigned with a full score are highlighted in yellow. And the highest total score is highlighted in green.*

4.2 Design Consideration

4.2.1 Quality

Quality is determined by the precision in fabrication and assembly processes. It is given the highest weight, since the prototype from the previous semester was not precise enough to be tested for microsurgery training. This was mainly because the mirror parts were not precisely implemented with desired locations and angles. Since material with higher precision can better achieve the goal of fixing optic parts, a higher score will be given for more precise fabrication and assembly processes. Though Grey Pro and Tough 1500 are processed at lower resolution than acrylic, the laser-cut acrylic parts must be manually assembled, which leads to more error and misalignment of the optic parts. Therefore, 4 out of 5 is given for Grey Pro and Tough 1500, and 1 is given for acrylic.

4.2.2 Durability

Durability is determined by the Young's moduli and ultimate stress of the materials. More durable material can provide better protection to the optic parts, avoiding fractures that undermine the performance of the design. While device performance is crucial for this project, safety concerns for the users shall also be emphasized by avoiding formation of sharp pieces from broken glassware. Therefore, durability is given the second highest weight. Grey Pro and acrylic have similar material properties, and they are given a 5 out of 5 for this category. A score of 3 is given for Tough 1500 for its lower mechanical strength.

4.2.3 Ease of Fabrication

Ease of fabrication is determined by the processing time of each material. The team is expecting to have multiple iterations of prototypes over the semester, so faster fabrication speed enables more prompt testing and re-design cycles. The team acknowledges that there are other factors that may be considered in this category, for example, the access of the equipment or refining the prototypes. However, since both 3D printers and laser cutters are less accessible in less-developed regions, access to the equipment is equally scarce for all the materials. Meanwhile, the inside of the design is hollow, and pulling out supporting structures in 3D-printed models leads to a similar level of inconvenience compared to assembly of the acrylic parts. Therefore, the team only considers the processing time by 3D-printers and laser cutters in this category, and acrylic is given the highest score for the highest processing speed.

4.2.4 Cost

Cost is an important factor for the project, since as is stated in the PDS, the project aims to provide an affordable solution compared to the expensive exoscopes. Cost is not weighted as much as the first three categories, since the cost to produce our current design is similar for all three materials. Yet, cutting parts from a large acrylic board will result in more waste of the material. Thus in consideration of cost-efficiency, acrylic receives the lowest score for the category.

4.2.5 Stability

Stability is determined by how well the material could fix the optical parts in place upon shaking or moving. The category is weighted less, because ideally high precision processing will maximize the fixation of the optic parts. However, because optic parts will be inserted to a frame made of the materials in the design matrix, the parts will not be perfectly held at their desired locations, and movement of optic parts in the design is almost inevitable. Thus, stability is listed as an independent category of quality. It is expected that the extra space for movement of optic components will be reduced with less parts involved in assembly. Grey Pro and Tough 1500 are given the highest score, since only one component will be made with the material; acrylic is expected to have the lowest level of stability, since more parts for the frame lead to more error in assembly, which then leads to less stability.

4.2.6 Safety

Though safety is an important factor for engineering ethics concern, all materials have similar but non-severe health hazards during fabrication. Grey Pro and Tough 1500 are in their liquid form prior to printing, which also requires UV light to cure the material to make them tougher. Though may be less harmful in a closed working environment, liquid irritation and UV damage are still considerably more hazardous than a truly enclosed environment for laser cutting. Therefore, 4 out of 5 is given for Grey Pro and Rough 1500.

4.3 Proposed Final Design

After evaluating the materials against PDS and proposed criteria, Grey Pro receives the highest score, which thus becomes the choice of material for fabrication.

5. Fabrication/Development Process

5.1 Materials

The materials required for the design include an iPhone 8 and an iPhone 10 with WiFi access, a Google Cardboard virtual reality headset, a metal stand to hold the iPhone, the grey pro resin for the housing, and an application for live viewing between the iPhone and the virtual reality headset. The team already possesses the iPhones necessary, the Google Cardboard headset, the application, the mirrors, and the stand. The only material left to obtain is the grey pro resin that will be purchased and used to 3D print the housing for the mirrors.

5.2 Methods

The team will use a program called Zemax OpticLabs to determine the final mirror angles to be placed in the housing. The housing will then be designed using computer software and printed at the TeamLab before inserting the mirrors into the final mold. An application will be downloaded onto the iPhone in order to share the camera view in live time with the computer screen. Ideally the application will provide minimal lag, so a cord may be connected between the two phones for optimal relay time. The stand will be used to correctly align the iPhone to view the sutures on the workbench at the correct level of zoom. The image shown from the iPhone camera will be relayed to the virtual reality headset using the application that the operator previously downloaded.

5.3 Testing

In order to test, the team will meet back with our clients, including a microsurgeon teacher, Dr. Weifeng Zeng, at the UW hospital in the Neurology Department. The team will set up the prototype and align the camera on the workbench. The team has previously attempted a practice activity with Dr. Zeng using the microscope that is currently used for microsurgery practice. Team members will attempt this practice activity again using the prototype and will compare the amount of time taken to complete it with the original attempted practice. The activity involves moving sutures from one box drawn onto a piece of fabric to another drawn-on box using two sets of medical forceps.

Discussion

Future Work

The team will continue with the grey pro resin material for the housing, which has been chosen as the most feasible for the design. This is a relatively inexpensive material that can be easily obtained and utilized at the MakerSpace in the University of Wisconsin building, Wendt Commons. The team will continue to work on finalizing the mirror angles and improving the field of view shown in the headset moving forward and will hopefully be able to soon begin printing and fabricating the housing. Following the printing of the housing, the team hopes to complete fabrication in one to two weeks and hopes to test by the end of March 2022. After comparing the results of the prototype with the results of the professional grade microscope, the team will be able to make alterations and continue to refine the prototype before the end of the semester.

Conclusions

The team has made significant progress in understanding the necessary components of binocular vision in order to successfully teach microsurgery to students. The current design has a promising outlook and the purchasing of materials, fabrication, and testing will ideally be completed before the end of March 2022.

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Appendix

A. *Product Design Specification*

Product Design Specification (PDS)

Title: iPhone Virtual Reality Training Model for Microsurgical Practice.

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September 24th, 2021

Function:
This training model will make microsurgical training less expensive and more accessible to a wide range of users. It eliminates the need for an expensive surgical microscope by replacing it with a smartphone. The prototype will utilize the zoom functionality of the smartphone for the surgeon to clearly see sutures and tissues up close. By using a smartphone, it is also possible to stream the training to Zoom or a similar platform so training can occur virtually. The design will minimize lag time between the recording phone and projecting device for simultaneous view of both the trainee and observers, while increasing spatial awareness and depth perception via binocular live video.

Client requirements:
- Must allow for depth perception with regard to where the trainee's hands are in relation to the work site.
- Must create an image with high enough zoom and resolution to see sutures (0.070 mm in diameter) clearly [1]
- Must remain inexpensive so it is widely accessible to training surgeons
- Must produce a streaming resolution of at least 10.2 megapixels
- Must have a stream delay of no more than 0.5 seconds
- Should utilize full magnification power of the smartphone

Design requirements:

1. **Physical and Operational Characteristics**

    a. **Performance requirements:**
        i. The device must be able to provide a clear image of the subject in a clinical environment. The device must be able to handle daily use and must be able to handle a load of at least 400g, the weight of the heaviest available smartphones.

    b. **Safety:**
        i. The device should be out of the way of the surgeon to prevent interference during practice. The device also needs to be able to be

sterilized in an efficient manner before and after each use.

c. **Accuracy and Reliability:**
    i. The device should be able to consistently maintain a magnification of 2x and the displayed magnification should be accurate with repeated trials. The device should display an accurate and clear image of the surgery area with minimal latency.

d. **Life in Service:**
    i. The device should withstand continued use over the duration of the training process, the longest of which can last up to 12 hours. The device should be able to withstand this use everyday over its lifespan, as many different trainees may use the device.

e. **Shelf Life:**
    i. The device should be stored in normal interior conditions. After six months without use, a lithium ion battery may begin to degrade. With continued use, the team would expect the smartphone being the limiting factor for the whole design. Thus, the final deliverable should have at least one year of lifespan, which matches the lithium battery warranty provided by Apple. [2]

f. **Operating Environment:**
    i. The product will most likely be used in a domestic or indoor environment, so the device will not be exposed to extreme conditions.
    ii. 0-35 ° C operating temperature, - 20-45 ° C nonoperating temperature, 5-95% non-condensing, relative humidity (the specification of iPhone 8, and more restriction may be applied as other hardware is introduced to the final deliverable) [3]
    iii. The person who will use this will be the trainee, which is the person who is practicing surgery using the iphone, and the trainer(s) who is/are watching the trainee on the headset.
    iv. Potential splash of food dye, blood, in vitro tissues, etc. [4]
    v. Components that are exposed to the operation station shall not be malfunctioned upon such splash
    vi. Potential scratches from the surgical equipment, such as tweezers or needles.
    vii. The final deliverable should at least endure accidental damage from the aforementioned scenarios, while maintaining the resolution to recognize the suture

g. **Ergonomics:**
    i. The product can involve somewhat delicate technology, such as smart phones and laptops, so the same restrictions of force that cause those devices not to be damaged or break apply here.
    ii. For the iPhone 8, do not submerge in water greater than 1 meter and for longer than 30 minutes. [3]

h. Size:

i. Should be able to be set up in an indoor living space (i.e. 10 x 10 sqft, approximately 3 x 3 meters)

i. Weight:

i. Optimum weight: < 10lbs (approximately 4.5 kg). Must be easily transportable

j. Materials:

i. No restrictions on material mechanics
ii. Cannot be toxic upon skin contact or inhalation
iii. Shall have minimal degradation resistance, such as from sunlight

k. Aesthetics, Appearance, and Finish:

i. The color of the product should be dull so that it doesn't distract from the microsurgical practice it is intended for. The shape and form should be adjustable so that each user/consumer can place it into alternate positions to get a better and more comfortable practice for themselves. The texture of the finish should be flat and soft in order for it to be comfortable for the user and in order for it to not be a distraction.
ii. Should simulate the working condition of an operation room with microscopes
iii. Must not interfere with the operation and training performance of the user

1. Production Characteristics

a. **Quantity:**

i. Tens of Thousands of units will be needed so that this can replace all current expensive training mechanisms for microsurgical practice for medical residents.

b. **Target Product Cost:**

i. The target cost of the product is undetermined thus far until clients discuss but it will need to allow for an iPhone, a stand, and any attachment that is necessary to put over the camera to replicate microsurgery practice as best as possible. There are existing products whose costs are at least $100,000 [5] which is drastically greater than the target cost. The prototype is a cheap alternative for medical students to use for remote training, using materials that are commonly owned.

2. Miscellaneous

a. Standards and Specifications:

i. ISO 10936-1:2017
   - Specifies the requirements for microscopes used during surgical procedures, so the team must adhere to these specifications when creating a design. However, since this prototype will be used for practice purposes, the requirements many not all apply [6]

ii. Code of Federal Regulations Title 21, Volume 8, Sec. 882.4525 Microsurgical instrument [7]
   - The final deliverable will fall into the Class I medical device category, which is exempt from the premarket notification procedures 510(k)

iii. Code of Federal Regulations Title 21, Volume 8, Sec. 878.4700 Surgical microscope and accessories [8]
   - The final deliverable, under definition of this section, will be a Class I device. However, since the recording device in this design will be a DC powered smartphone, no more actions shall be made upon this regulation

b. **Customer:**

i. The customer would prefer the delay of relaying the image to the headset to be minimized for enhance practicing technique (less than 0.5 s)

ii. The quality of the camera while zooming should be clear enough to clearly see the material being worked upon. 2x zoom using an iPhone 11 Pro was tested to be the most practical. The requirement is that the trainee is able to see the suture, which is 0.070 mm [1]

iii. The camera should be able to show the depth of the workspace in order to help determine the distance between the instruments being utilized and the suture on the workbench. This may require the use of two lenses to allow for a binocular view

iv. The device should be comfortable to wear for extended periods of time

c. **Patient-related concerns:**

i. As this is a device used for practice, there will be no requirements for patient confidentiality.

ii. Sterilization should not be an issue with regard to the camera setup. However, it may be practical to clean the headset with a wipe between uses.

d. **Competition**:

i. Augmented Reality (Mixed Reality)
The Microsoft Hololens is a very complex device which allows for similar types of practice. However, the Hololens is much less accessible and much more expensive. This will be an alternative that is possible to use from many different remote locations.

Meanwhile, mixed reality provided by Hololens is rather redundant for the purpose of the clients. [9]

ii. Exoscopic Platforms

Zeiss, Olympus and Mitaka are well known medical device providers for exoscopes, featuring high definition images of the field with 8x to 30x magnifying capability. However, the price varies from 0.2 to 1.5 million dollars, resulting in limited access for trainees from less developed regions [5].

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