IPHONE VIRTUAL REALITY TRAINING MODEL FOR MICROSURGICAL PRACTICE

Preliminary Report | Oct 6th, 2020

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Course: BME Design 400

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Abstract

Medical training technology has been growing as complex models and simulations have made it cheaper and easier to train medical students and professionals outside of real procedure observation and practice. The world at large can benefit from cheaper training technology as developing countries have a demand for increased medical training but lack the wealth to obtain expensive medical equipment. One area of improvement is microsurgery, which commonly requires expensive equipment for doctors to practice and perform surgery. Products on the market such as the eoMicro allow surgeons to practice at home with little equipment needed for around $100, however, issues of streaming delay and depth perception persist. Our client has plans for developing and distributing an inexpensive microsurgery training “kit” using minimal supplementary equipment and primarily consisting of commonly owned items such as smartphones and laptops. Magnification from the smartphone cameras provide a view of the microsurgery training area while the footage is streamed on a screen for comfortable viewing while practicing. What remains to be solved is a reduction in latency between video streaming and camera recording to improve operator precision, as well as a need to develop video depth perception potentially using 3D for optimal surgical performance. Several hardware configurations and video modifying software are being evaluated to overcome these issues.

I. Introduction

1.1 Motivation

Surgical microscope is the most expensive and space-occupying device used in microsurgery. In developing countries, microscopes are not always available and used in operating rooms where they are needed most [1] . Lack of resources and trained personnel in low and middle income countries lead to inaccurate diagnosis and inadequate treatment [2] . Affordable and effective surgical microscopes have the potential to significantly improve disease detection rate in undeveloped countries where diagnostic laboratories are scarce [1]. Inexpensive home microsurgical equipment allow resident surgeons to have more opportunities practicing and improving their skills.

1.2 Existing Devices

1.2.1 eoMicro simulator

Figure 1: eoMicro simulator. The eoMicro simulator in combination with a smartphone creates a home microsurgical set-up that allows microsurgical skill improvement [3]

The eoMicro simulator is a low-cost and portable home microsurgical set-up. It consists of a plat-pack platform which allows the trainee to use it in combination with a smartphone to practice microsurgical procedures and improve his or her microsurgical skills. But this model fails in truly simulating a surgical microscope which magnifies the three-dimensional operation. The trainee cannot have real-time feedback and correction from their mentors about their practice.

1.2.2 3D viewing system

Figure 2: Integrated video camera in observer scope streams the real-time video to the 3D monitor Surgeons are using a 3D surgical viewing system that displays the procedure on a 3D monitor in the operating room so that the entire operation could be observed by the team. [4]

1.2.3 Client Current Model

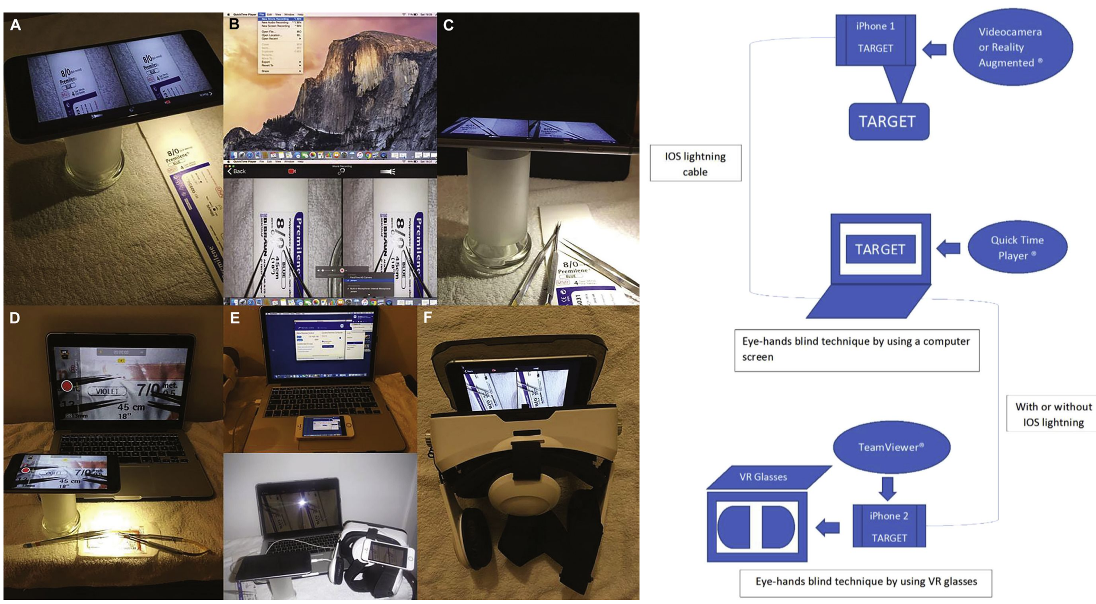

Figure 3: Setup of the training model and schematic illustration of the equipment. The iPhone(#1) is connected to a Macbook and it is placed on a holder to record the surgical target field. This iPhone(#1) is used as the webcam of the computer. The video is duplicated by Reality Augmented (a computer specific software) and transferred from the computer to iPhone(#2) which is connected to virtual reality glasses. [5]

This model is designed for any medical student, resident, fellow, or surgeon with almost no-extra cost, as it is based on “technological tools” that are already mostly owned by any trainee (iPhones or other smartphones, personal computers). The first iPhone is placed on a holder at a height 15 to 20 cm from the surgical target field and connected to the Macbook to work as the webcam. The video is duplicated by Reality Augmented (a computer specific software) and transferred from the computer to the second iPhone which is connected to virtual reality glasses.The use of virtual reality glasses creates a stereoscopic 3D image by angling two 2D images, therefore, creating an illusion of depth to the image. This setup is able to provide comparable magnification and adequate depth perception to truly simulate a surgical microscope. But the latency of video streaming remains and the VR glasses have some limitations in offering high-resolution images.

1.3 Problem Statement

Microsurgical training is relevant across several surgical specialties, including neurosurgery, vascular surgery, otolaryngology, ophthalmology, and plastic surgery[3,6,7]. It is technically challenging to master manual skills because of the complexity of microsurgery, such as the use of fine instruments (with a tip precision of 0.025 mm) and handling delicate tissues [5]. Therefore, a continuous training process and detailed feedback on skills components are required for microsurgical residents to refine precise technical skills, develop eye-hand coordination, and a high level of dexterity [8].

Effective training to develop microsurgical skills requires at least 2×–5× magnification of the surgical field, but the surgical microscopes are expensive[9] and well-equipped microsurgical labs are only available in advanced countries. As a result, many residents have little or no opportunities to learn and practice microsurgical skills due to lack of high-cost equipment.[5, 10]. Thanks to modern technology, the camera capabilities of an iPhone provide such incredible magnification that they are comparable to surgical microscopes[10, 11]. An iPhone with 8 or more megapixel camera is able to record videos from 720p HD at 30fps (frames per second) to 4K at 60 fps. Although iPhones alone are not able to simulate a surgical microscope due to its lack of stereoscopic view, the application of VR glasses displays the procedure on a 3D view and enables more accurate operation[10].

The client has attempted to create this model using a computer, two cell phones, VR glasses and lightning cable connection, However, there is too much delay from this current mode, so a simple streamlined iPhone-VR system is proposed to create a home microsurgery simulation tool for resident surgeons to practice skills.

II. Background

2.1 Client Information

Our client is Dr. Ellen Shaffrey, a plastic surgery resident in Dr. Samuel Poore's plastic surgery lab at the Department of Surgery in the University of Wisconsin School of Medicine and Public Health. Dr. Shaffrey made a proposal for a series of devices to simulate a microsurgery training environment at one's home, named "iPhone virtual reality training model for microsurgical practice". Despite having virtual reality in the name, the real function of the device is to establish depth perception for its user when they perform microsurgery training. The client had also developed 3 prototypes of her own to experiment with different setups to achieve a functioning training environment. The first: an iPhone on a stand connected to Macbook. The second: a VR App on an iPhone creating two images. The third: an iPhone on a stand connected to a Macbook with Google VR cardboard glasses. Each of these had limitations, however. Respectively, Quicktime does not rotate to widescreen from iPhone and there was a slight time delay, poor zoom, and 0.5-1sec delay when no cable and cannot modify the iPhone when wearing the glasses. The BME team will proceed with these prototypes in mind to develop an effective system with low latency and video footage with depth perception.

2.2 Magnification of Microscope and iPhone

The professional microscope that the client uses for microsurgery is the Mitaka MM51, which is capable of up to 42x magnification while using a 4K camera and monitor. The level of zoom is 8:1 [12]. The client is testing options of the iPhone 8 and iPhone XR which have 4K video recording at 24/30/60fps and 2x optical, 10x digital zoom and 4K video recording at 24/30/60fps and 3x digital zoom, respectively [13] [14]. In this case, the iPhone 8 meets the minimum requirements for the magnification required for some microsurgery. The iPhones' screens are not optimal for viewing, and instead a separate screen is expected to stream their video footage.

Figure 4: The entire Mitaka MM51 system

Figure 5: The iPhone 8 and iPhone XR and their cameras

2.3 Depth Perception

Depth perception is an important feature for the device as it allows the user to properly judge the distance their hands are from the camera and perform the necessary delicate actions of surgery. Depth perception can be considered seeing objects in 3D which is one of the ultimate goals for the device. Vision can be differentiated between monocular and binocular vision, where binocular vision is the feature that allows for depth perception. Binocular vision is achieved by having two similar views of the same perspective with one view being slightly offset from the other. Humans have two eyes which can achieve this, and the two images are fused into one in the brain with the ability to infer the relative distance between objects.

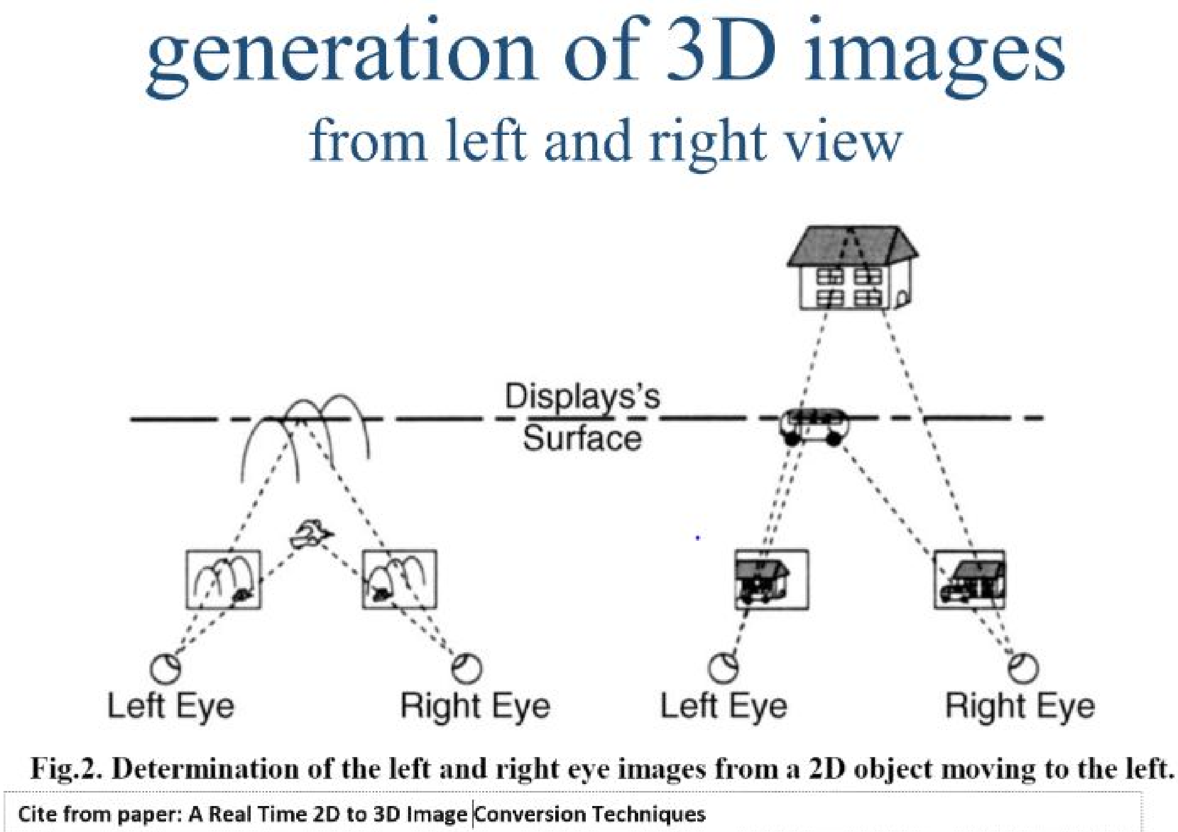

Figure 6: An example of how 3D is achieved using offset images from two different viewpoints

Cameras with a single lens can only achieve monocular vision, so there are issues with hand-eye coordination if you rely on footage from a camera to control your hands. This is the case when using a smartphone for magnification. However, there are ways to digitally create a 3D perspective when using a single lens. One strategy is through the use of Depth Image-Based Rendering (DIBR) and algorithms, which have multiple approaches. The main principle is that the depth map of a stream is generated through values saved for each pixel that represent how far the pixel is from the camera. First, the current texture image and a stationary scene image, which is extracted from the input video, are warped to the same virtual perspective position by the DIBR method. Then, the two virtual images are merged together to reduce the hole regions and maintain the temporal consistency of these areas. Finally, an oriented exemplar-based inpainting method is utilized to eliminate the remaining holes [13].

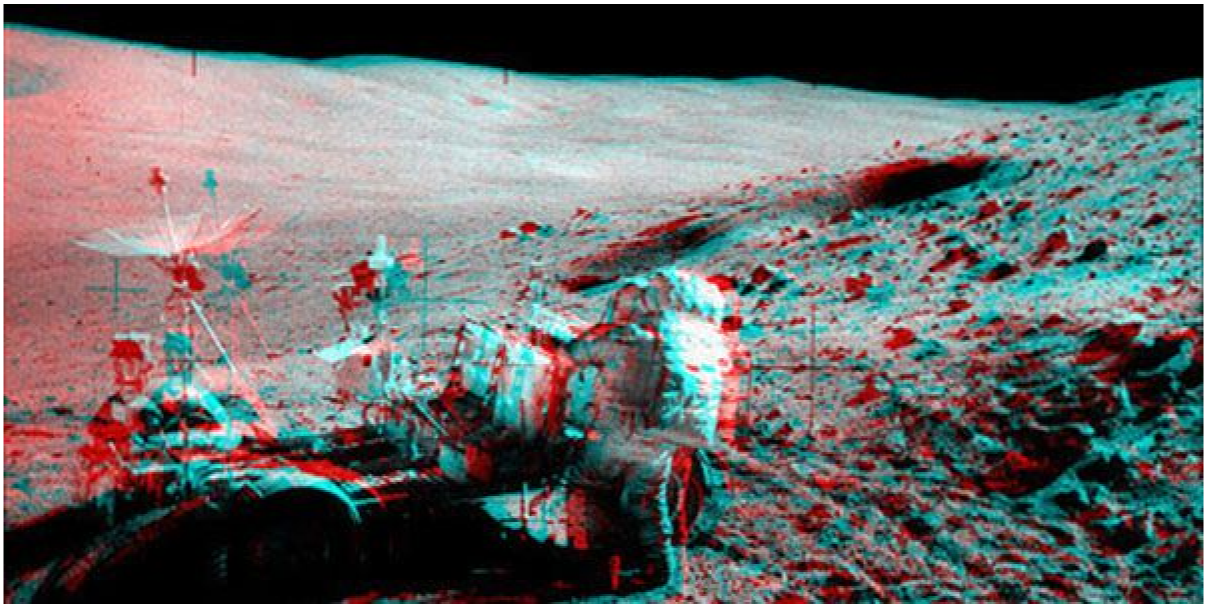

Figure 7: An anaglyph image showing the cyan and red images offset from each other

A 3D effect can also be achieved using anaglyphs, which is the technology used for blue-red 3D glasses. Anaglyph images are used to provide a stereoscopic 3D effect, when viewed with glasses where the two lenses are different (usually chromatically opposite) colors, such as red and cyan. Images are made up of two color layers, superimposed, but offset with respect to each other to produce a depth effect. Usually the main subject is in the center, while the foreground and background are shifted laterally in opposite directions. The picture contains two differently filtered colored images, one for each eye. When viewed through the 'color coded' 'anaglyph glasses', they reveal an integrated stereoscopic image. The visual cortex of the brain fuses this into perception of a three dimensional scene or composition [15]. In the end, these effects are achieved through digital filtering with minor analog components to complete them.

2.4 Design Specifications

The client has already developed prototypes of their own and has determined that for a camera 4x/5x/6x magnification and up to 15x/20x/25x magnification is necessary for viewing smaller blood vessels. This magnification needs to be adjustable and not fixed for user convenience. The range of field for the camera is not large as it is close to what it is viewing, and peripheral vision is not necessary as the focus is on a small feature. The main focus for the current project is to lower the delay time between devices and create a sense of depth perception for the viewer. A secondary feature for the device is that the setup should be rather affordable, preferably no more than $100 for the cost of items outside of smartphones and laptops, to be appealing compared to competing products on the market. The device should take into mind any motion sickness a user can experience while using it as developing an artificial sense of depth may be headache inducing.

III. Preliminary Designs

3.1 3D Glasses Model

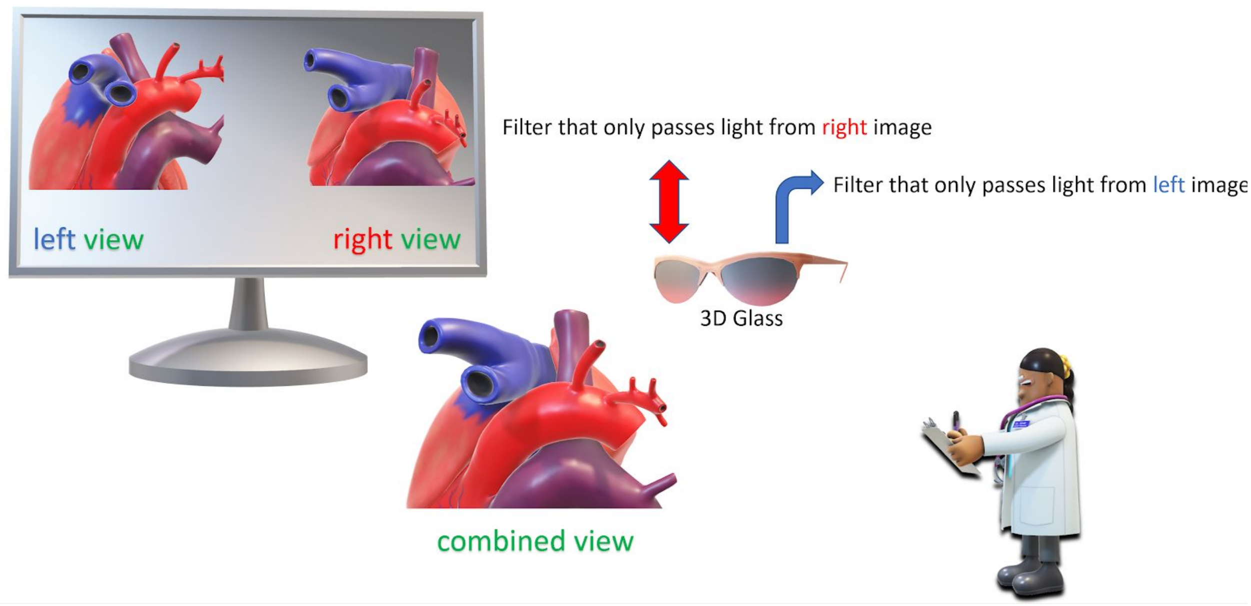

Figure 8. The Concept of 3D Glasses Model. The 3D Glasses Model consists of active 3D glasses with a big screen displaying 3D compatible images.

The first model is the 3D glasses model. As the name suggests, the 3D glasses model uses active 3D glasses with a screen casting the image from the camera. We plan to use software methods such as anaglyph or hardware methods like a 2D to 3D convertor to process the image. While practicing surgeries, the trainee will wear 3D glasses and look at a screen in front of the trainee. This might be a little bit different from traditional surgeries that may look down for what surgeons are doing on their hand. The 3D glasses will be much lighter than the VR goggles and thus have less stress placed on the nasal bone. In addition, since the 3D glasses do not have a screen directly in front of the user's eyes, it is less likely to cause potential vision uncomfortableness during usage.

3.2 VR Goggle Model

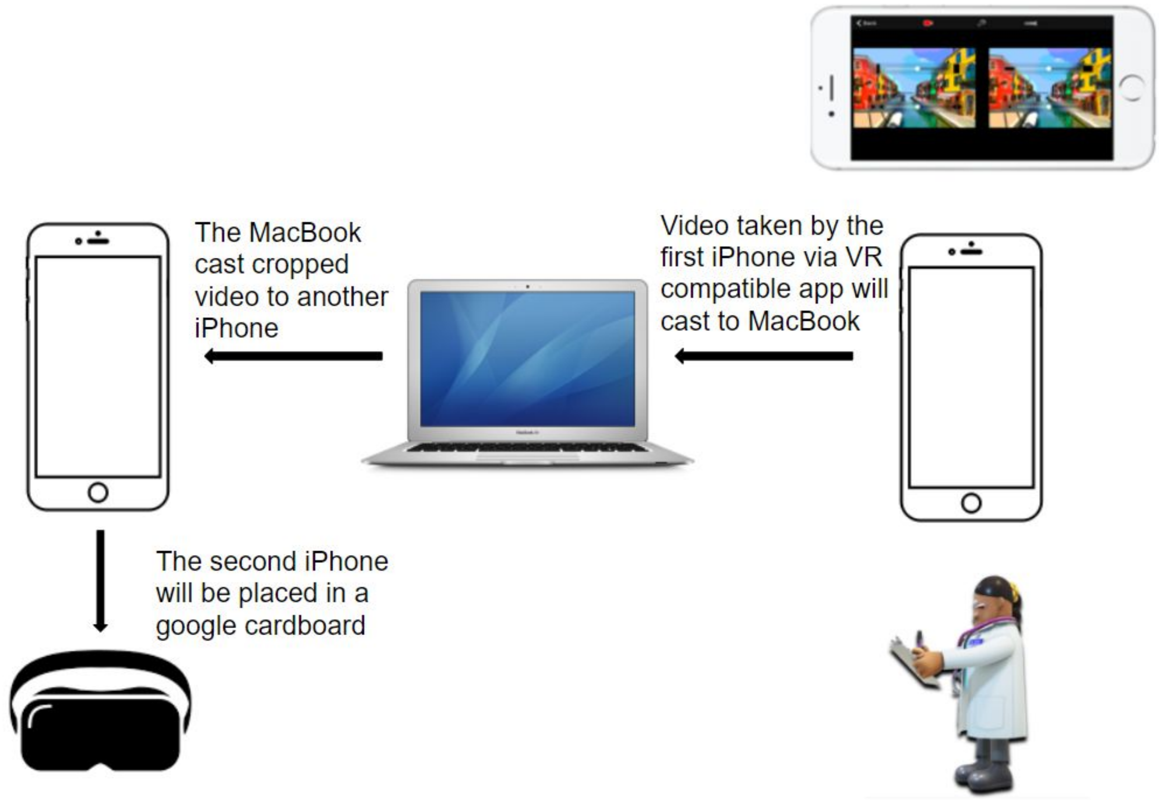

Figure 9. The Concept of VR Goggle Model. The VR Goggle Model consists of two iPhones, a MacBook, and a VR set. One of the iPhone in this model is for capturing the image of the surgery, and another iPhone is for displaying the processed image onto VR goggles.

The second model is the VR goggle model. This model uses a VR headset instead of the 3D glasses. The other parts of this model include two iPhones and one MacBook. One of the iPhones will serve as the camera for the platform. The iPhone will use an Application from the Apple Store called Reality Augmented. This application will split the camera image into two so that it will be viewable with a VR headset (as shown in the upper right). Then the split image will be casted to a MacBook, and the MacBook will process the image to crop the margin of the iPhone screen. Finally, another iPhone will receive the cropped image and display the image via the VR headset such as Google cardboard.

This setup will allow us to have a better resolution with the iPhone's camera and better vision effect with the VR technology. However, the data transferring between the three devices might cause a noticeable delay for moving objects. In addition, the application Reality Augmented does not have the function of zooming so that the focal distance between the camera and the object will be fixed.

3.3 WebCam VR Model

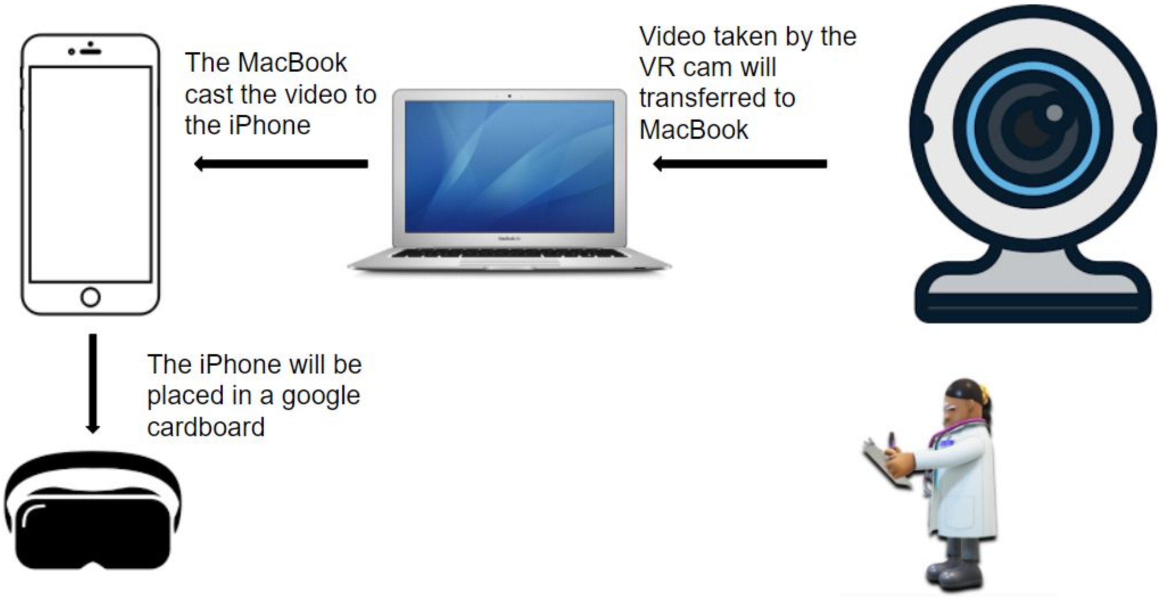

Figure 10. The Concept of WebCam VR Model. The WebCam VR Model has a very similar setup as the VR goggle model. The change we made for this model is that we replaced the first iPhone which serves as the camera with an actual VR camera.

The third model is the WebCam VR model. We used a VR webcam instead of an iPhone in this model to achieve a better VR compatible experience and zooming ability. There are already commercial VR cameras for streaming purposes. In this case, the camera will be able to display the VR compatible image directly on laptops and the delay between devices will be minimized. We anticipate that by using a webcam, it will be much easier to set up the platform and have a good quality of vision as well. After the image is transferred to the MacBook, the rest of the steps will be pretty much similar to the VR goggles model; the macbook will cast the image to an iPhone and then the iPhone will be placed in VR goggles. In this case, the user will be able to look at the object with the zoom they desire.

IV. Preliminary Design Evaluation

4.1 Design Matrix

Table 1. The Design Matrix of Three Models and Evaluation Results.

	3D Glasses	VR Goggles	Webcam VR

Efficiency (30)	5/5	30	2/5	12	4/5	24
Complexity (25)	4/5	20	2/5	10	2/5	10
Feasibility (20)	3/5	12	4/5	16	4/5	16
Quality (15)	3/5	9	3/5	9	5/5	15
Cost (5)	5/5	5	3/5	3	4/5	4
Safety(5)	4/5	4	3/5	3	3/5	3
Total (100)	80		53		72	

Table 1

4.2 Design Consideration

4.2.1 Efficiency

The first criteria we evaluated is the efficiency of the device. We analyzed the speed of the connection between each device for the three models. In other words, we estimated how fast the image transaction and conversion compared among those models, and the potential delay it may cause. The 3D glasses model got the highest score, because the other two VR models all require data transaction from a camera to a MacBook, and then from the MacBook to an iPhone. However, the 3D glasses model only needs a camera and a large screen to display the image. Therefore, we anticipate that the data transaction in the 3D glasses model will be fastest among the three models.

4.2.2 Complexity

The complexity mainly looks for the amount of devices that will be incorporated into the overall design. It is clear from the setup of the platform that the 3D glasses model has the fewest devices required, which is a camera and a TV or monitor. Nevertheless, both of the models that use VR headset require at least three devices including an iPhone, a MacBook, and a webcam or an additional iPhone.

4.2.3 Feasibility

In order to evaluate the feasibility of the three models, we asked the question if we can make the device using the skills we have learned and the technology available to us. For the VR goggles model and the WebCam VR model, we only have to correctly connect each device and find the best application for camera and casting. Nonetheless, as for the 3D glasses model, we probably will have to code for the conversion between the 2D and 3D image. The concept of anaglyph is not hard to understand, but compared to the both VR models, the score of the 3D glasses model will be relatively lower.

4.2.4 Quality

The criteria of quality examines the quality of image for the user. We believe that the VR webcam will have the highest quality of image because the camera is specifically designed for VR videos. Even though the iPhone also has great cameras, the quality of the image may be lost during the transaction and process through the application.

4.2.5 Cost

We calculated the cost of each model and removed the device that people normally have. We expect every surgeon will have a smartphone and a laptop, and may have a TV at home. In this case, the cost of an additional smartphone will be the largest, while the cost for a camera in the 3D glasses model will be the cheapest.

4.2.6 Safety

As for the safety factor, we considered motion sickness caused during usage and wearing comfortableness. Since the VR headset will have a screen close to the user's eyes, the motion of the user or object may cause some discomfort for the user such as dazzling. Because the 3D glasses are light and are designed to look at the screen far from the user, the risk of having vision discomfort will be much lower. In addition, usually the head strap for the VR headset is very tight and long term usage of the VR set may cause pain to the user. Overall, the 3D glasses model got the highest score for the safety criteria.

V. Fabrication/Development Process

5.1 Materials:

5.2 Methods

5.3 Final Prototype

5.4 Testing

5.4.1 Preliminary Testing

5.4.2 Final Testing

VI. Results

VII. Discussion

7.1 Implication of Results

7.2 Ethical Considerations

7.3 Changes Made/Need to be Made As a Result of Evaluation

7.4 Sources of Error

VIII. Conclusions

8.1 Design Summary

8.2 Future Work

8.2.1 Software

8.2.2 Hardware

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X Appendix

Preliminary Product Design Specifications

Table of Contents

Function:

The clients' current model is combining virtual reality glasses with a computer, two cell phones, and a lightning cable connection to perform microsurgery. However, there is too much delay and the team is expected to design a simple streamlined iPhone-VR system to create a home microsurgery simulation tool that could be used as a resource for resident surgeons to practice microsurgery.

Client Requirements:

- Magnification: 1:12.
- Ensures an immersive experience for the entire surgical team due to its big-screen 3D imaging.
- Minimize the delay of real-time 3D imaging (currently around 1 ms)
- Make the model more streamlined with fewer devices. The expectation is to use a single iPhone for recording and casting to the Macbook screen so that surgeons could use VR glasses to directly look at the screen.

Design Requirements:

- *Performance Requirements:*
    - The device should be as fast as possible to improve the VR viewing experience
        - Minimize display lag between the smartphones and the MacBook
- *Safety:*
    - The device should minimize unnecessary visuals to the user's eyes
        - Not overly bright, no sudden flashes, reduce motion blur
- *Accuracy and Reliability:*
    - The ratio of the original camera image to the one seen should be maintained

- *Life in Service:*
  - The device should be able to be used multiple times for as long as the shelf life
- *Shelf Life:*
  - The device should ideally last as long as the smartphone/MacBook in use remains functional
- *Operating Environment*
  - The device will be exposed to normal conditions, such as room temperature, and will be used by resident surgeons
- *Ergonomics:*
  - The device should be fairly portable as it will likely be worn by the user
- *Size:*
  - The device should minimize the number of devices, such as smartphones and MacBooks, used.
- *Weight:*
  - The device currently consists of an iPhone XR (194g [1]), an iPhone 8(148g [2]), 1 Macbook 13” with retina display computer (1551g [3]), lightning cables (negligible), and an articulating arm phone mount stand (440g with a maximum load of 500g [4]). Therefore, the total amount of weight is estimated to be 2333g.
- *Materials:*
  - The device does not have certain materials that should be used for fabrication. However, the material used in the VR set should be considered. The current model is using google cardboard as our VR headset, and the material from the google cardboard such as the head strap may cause some uncomfortableness according to some customer reviews.
- *Aesthetics, Appearance, and Finish:*
  - The device aims to perform a mock surgery at home, so it should use as many materials available at home as possible. In this case, this platform will result in an iPhone clamped on the mount and connected to a MacBook Pro, and another iPhone will wirelessly be connected to the MacBook and placed in the google cardboard.

<u>Production Characteristics:</u>

- *Quantity:*
  - Nowadays, in developing countries, the demand for microsurgery, especially in the field of plastic surgery, has increased tremendously. It is estimated that in Zimbabwe there are only 0.03 plastic surgeons in every 100,000 people, which is a very low number compared to 1.98 plastic surgeons per 100,000 people in the United States [5]. Additionally, the lack of facilities for surgeons to practice will also cause high demand for experienced surgeons. In this case, the development

of a VR platform that mimics the surgical situation with depth perception will help surgeons in developing countries.

- *Target Product Cost:*
  - The current model requires two smartphones, one computer, a connection cable, and a smartphone stand mount, but in the future, we may reduce the smartphones or computers used in the product. We would assume that the user already has at least one smartphone and a cable. Thus, although the total cost of the product may vary, the maximum cost for this platform is to buy another smartphone, a computer, and a smartphone stand mount.

Miscellaneous:

- *Standards and Specifications:*
  - The device, similar to its current professional version used by surgeons, is a class 1 device and is exempt from requiring FDA Premarket Approval. To receive a CE mark for EU approval for a class I medical device, the device needs a Declaration of Conformity registered with a Competent Authority. ISO 10936-1:2017 specifies requirements and refers to test methods for operation microscopes used for observation during surgical operation and treatment of patients, but it does not apply to accessories, e.g. photographic cameras. [6]
- *Customer:*
  - The customer has a preference for the components of the device to be cheap and easy to obtain. There is potential to market the device in underdeveloped countries where there are limitations in money and technology available. The device should be able to hook up to external monitors for the potential viewing of students in a teaching environment. For better ease of use, the operator of the device should have the ability to adjust the zoom and move the optics of the device as needed without any trouble. The device needs a depth of field such that the operator is able to effectively wield instruments while using the device - however, the distance required is short, less than 30 centimeters in practice, and no peripheral vision is required. The client is considering between two iterations of the device, one iteration being stand-mounted, and the other being a form of headset the user wears, and both routes for the design still need to be evaluated for their practicality and performance.
- *Patient-Related Concerns:*
  - Whether it is used for training or for a real operation, the device comes into contact with its user and must be cleaned after every use. It should not, however, come into contact with a potential patient. The device does take footage of the operation, which requires the user's consent, and if it were to be used to operate on a patient, it would need the patient's consent.

- *Competition:*
  - The competition to this device is not an already used professional device such as what the client uses (MM51 YOH Surgical Microscope System, MSRP $310,000), but any proposed cheapened alternative that offers great magnification and resolution for microsurgical practices using as few components as possible. [7]
    - eoSurgical has microsurgery simulations using your own devices such as phones, tablets, and tv screens, but their cheapest product, the eoMicro, costs £82.50 ($106.84 USD). It has its own stand, which is rather bulky and cannot be used outside of training. [8]
    - Pocket Suture has a Pocket Microsurgery Trainer for $145.00. It is too simplistic for the client's needs by only requiring a phone and does not solve the client's problem with their current proposed device (the lag between devices). It is also only for individual training. [9]

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