IPHONE VIRTUAL REALITY TRAINING MODEL FOR MICROSURGICAL PRACTICE

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Abstract

Problem:
Currently, medical students and surgical residents have trouble gaining access to locations where microsurgical practice is possible due to the scarcity and cost of the large microscopes.

Purpose:
To design a prototype that is compatible with a single smartphone camera lens to reduce the cost and expand the availability of training to virtually any location across the globe. The video should be accessible via stream to another computer/phone with minimal lag for immediate feedback for microsurgical trainers. The prototype must provide stereoscopic vision which will allow users to utilize their depth perception to determine the distance between their hands and the surgical specimen.

Final Results:
The final design is a small housing containing angled mirrors capable of being attached to a phone's back camera. The mirrors work to split the field of view into two images and feed the images into the camera lens simultaneously. This splitting of the image creates binocular vision, thereby creating depth perception with a single lens. This image is then streamed to a virtual reality headset, where image transformations are performed. The student wears the headset while practicing to see a zoomed view of the surgical specimen with depth perception capabilities.

Background

- Microsurgery allows for the treatment of numerous health conditions.
- Microscopes required for training microsurgeons are expensive, inaccessible, and hard to relocate.
  - This leads to a large barrier to to training for various types of physicians across the globe [1].
- Modern smartphones have good magnification capabilities and are inexpensive, portable, and allow for remote use (during COVID pandemic) [2]
  - Many students have access to a smartphone from any location
- Smartphone cameras lack depth perception.
- This device seeks to provide the user with depth perception when viewing the surgical field [3]
  - Replicate the results of larger microscopes.

Design Specifications

- Lightweight; < 4.5 kg
- Adequate zoom and resolution to see sutures (0.07mm in diameter) [3]
- Stream delay < 0.5 seconds
- Capable of providing depth perception

Competing Designs

Mitaka MM51 microscope [4]
- High resolution at 160 line-pairs per millimeter
- 42x magnification
- 8:1 Zoom

Orbeye 4K 3D Orbital Camera System
- 4K 3D monitor for shared viewing. Real-life color gamut and depth perception.
- 26x magnification
- No image latency

Drawbacks of Existing Designs
- Expensive: ~$300,000
- Inaccessible: Have to travel to hospital or lab to use
- Hard to transport: Large, heavy, and bulky

Figure 1: Mitaka MM51 Microscope currently used in operating rooms. [2]

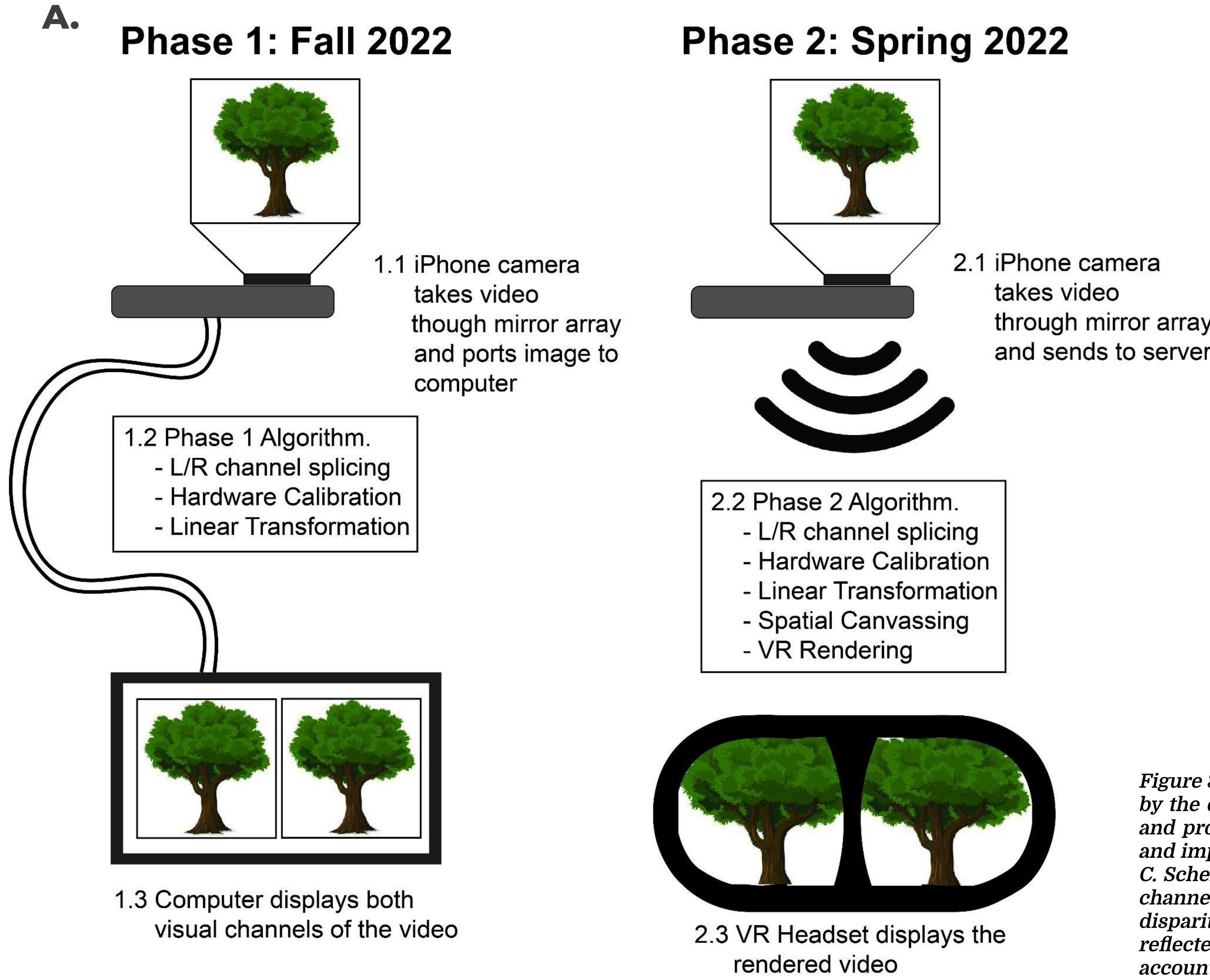
Materials

Table 1: Materials and Costs

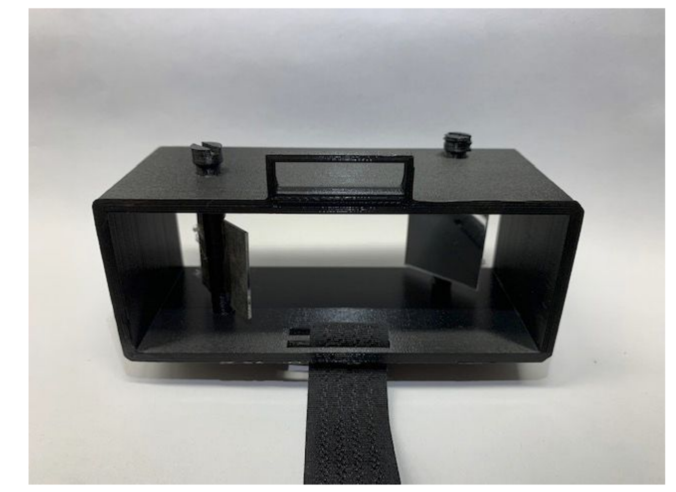
Component	Use	Cost
3D Printed Material, Grey Pro Resin	Housing	$4
1x1 inch Mirrors	Reflect image	$7.99
Oculus VR Headset	Stereoscopic display	Provided by client
Phone Boom Arm	Hold imaging device	Provided by client

Figure 2: Early proof-of-concept prototype design utilizing a double-mirror array fabricated from cardboard.

Final Design



B.



C.

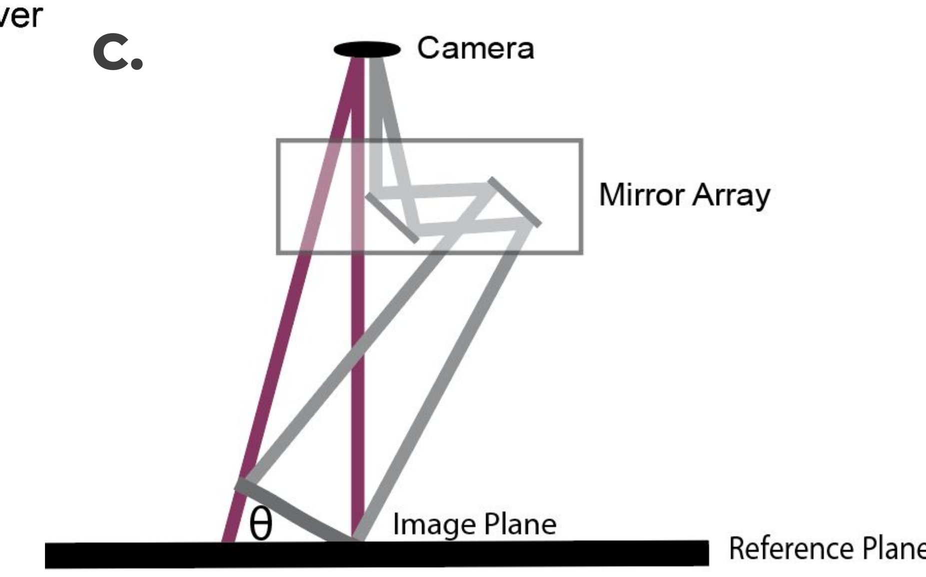
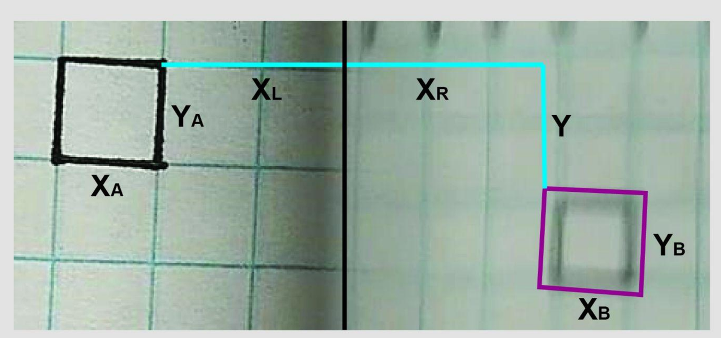


Figure 3: A. The two phases of the design's outlook. Phase 1 is defined by the definition of the mathematical basis of image transformation and programming of VR software; Phase 2 is defined by translation and implementation. B. Image of the 3D printed mirror array design. C. Schematic of the final design of the mirror array. Only one visual channel of the image is reflected by the mirror array to achieve a focal disparity of 60mm, the distance between human pupils. The singly reflected visual channel creates an inclined image plane to be accounted for during image transposition in VR.

Methodologies of Testing and Calibration



Calibration Angles

$$\Delta\phi_x = F \times arcsin(X_L - X_R)$$
$$\Delta\phi_y = F \times arcsin(Y)$$

Normalization

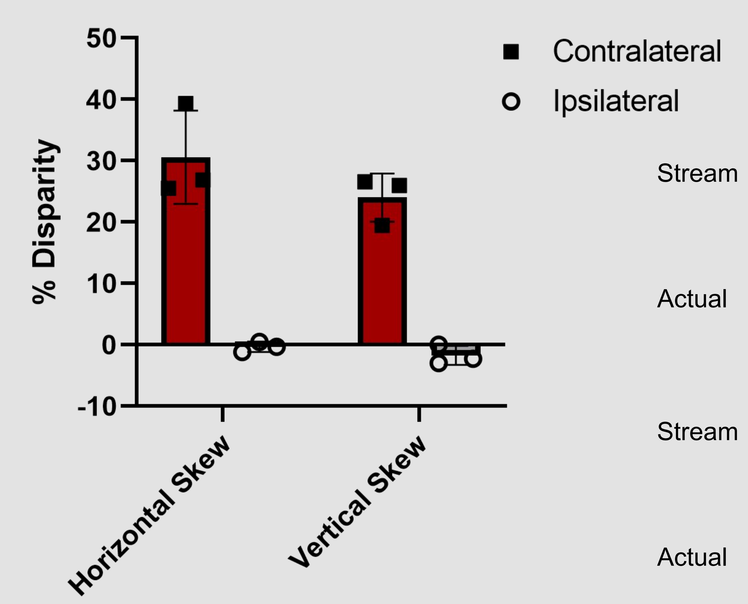
$$\mathbf{A} = \begin{bmatrix} X_A & 0 \\ 0 & Y_A \end{bmatrix} \quad \mathbf{B} = \begin{bmatrix} X_B & 0 \\ 0 & Y_B \end{bmatrix}$$

$$define\ \ \mathbf{S} \in \mathbb{R} = \begin{bmatrix} \cos(\theta) & 0 \\ 0 & 1 \end{bmatrix}$$

$$det(\mathbf{A}) = det(\mathbf{B} \times \mathbf{S}) = Area = xycos(\theta)$$

Figure 4: Top. Example image used during calibration and normalization of the two visual channels. A square of 1 cm^2 area was drawn on graph paper and was imaged using the focused mirror array. The lengths and widths of the two squares were measured as well as the disparities in the horizontal and vertical directions. Bottom. Disparities were used to calculate calibration angles for adjusting the alignment of the mirror array. More, the size of an object viewed in both channels can be normalized by a defined transformation matrix S. These calibrations will define the canvas position of the two visual channels during phase 2.

Results



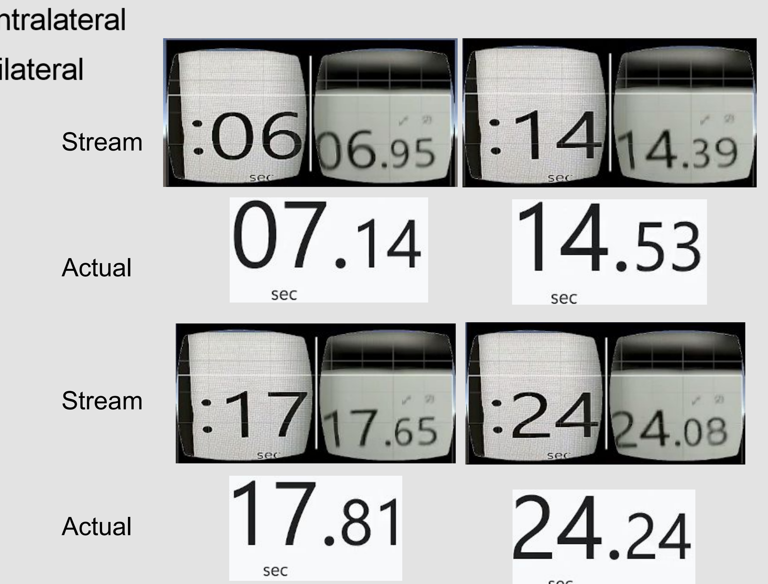


Figure 5: Left. The % Disparity in length of an object imaged from both visual channels of the mirror array. Skew in both the horizontal (p < 0.0001) and vertical (p < 0.0001) in contralateral comparisons were concluded to have a statistically significant difference from controls obtained in ipsilateral channels (n=3). An average % disparity of 30.59% was obtained in the horizontal direction, and a % disparity of 24.01% was obtained in the vertical direction, corresponding to a 52.75% reduction in area in contralateral comparison. Notably, no rotation was observed in contralateral comparison. Error bars represent SEM. Right. Marginal time delays were observed during server routing of a live video. An average of 150 ms was observed in multiple trials over a 30 second time interval, and no changes in latency were observed over longer trials >30 minutes.

Discussion

- The misalignment in the images and discrepancies in area undermine image quality but can be accounted for in front-end processing
- Improvements can be made in mirror and 3D printing quality
- Final mirror array design concept improves compactness
- Appropriate parameters are an ongoing conversation
- Sub-threshold latency in live-streamed videos shows promise for real-time virtual reality application

Conclusion

- The goal for the semester was to develop a framework and code for a virtual reality application
- Ultimately, the prototype should give medical students the access to practice microsurgery through a single lens that provides depth perception
- Some of the most important goals achieved are:
  - A small prototype that is immensely easier to transport and set up compared to current, alternative microscope
  - Stereoscopic vision, which gives a sense of depth perception
  - The ability for students to practice from any location, regardless of distance to the nearest laboratory
  - Compatibility with a smartphone, which virtually every student owns
  - A significant cost reduction from currently alternative microscopes
  - Stable housing of the prototype to prevent movement of the mirrors
  - Improved image quality
  - Minimization of blindspots in the image
- Among goals not achieved, additional experimental data was obtained for calibration of the design for application in VR
- This prototype may also have implications beyond the medical field, providing alternative to virtual reality products that are currently available.

Future Work

- Create compact mirror array for reflection of both visual channels
- Complete programming to push smartphone livestream to Oculus VR
- Implement low-latency software to clean up the video
- Implement manual or automatic focus feature to increase clarity
- Perform testing with surgical trainees to assess the device's performance
- Implement a stable attachment point to the mirror array for increased stability

References

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Acknowledgements

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