Design of an Alternative Method to Create Custom Ocular Prosthetics

Utilizing 3D Technology in the Ocularistry Industry to Improve Accessibility, Affordability, and Patient Comfort

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Biomedical Engineering

By
Raina Danielle Mourad

Fall 2021

Technical Project Team Members
Jaden G. Stanford

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISORS

Benjamin Laugelli, Department of Engineering and Society

William Guilford, Department of Biomedical Engineering

Introduction: Socio-Technical Research Problem

In Fairfax, Virginia, a high school English teacher prepares daily lessons and meets with students. He is a well-loved teacher among the students and faculty. Each morning, this same English teacher cleans his ocular prosthesis and carefully places it underneath the lids of his empty eye socket, similar to a contact lens. Like this English teacher, many people wear ocular prosthetics to restore a normal facial appearance.

Enucleation, or surgical removal of an eye, is an irreversible procedure that affects new patients each year. When the eye is removed, the lost volume is replaced with a spherical implant to maintain facial symmetry. Afterwards, the patient's conjunctiva is sewn across the top of the implant, leaving a layer of pink eye tissue exposed (Moshfeghi et al., 2000). Post-surgery, in attempts to regain a natural look, patients have the option of receiving either a custom or stock ocular prosthesis; custom prosthetics are recommended because of their superior fit and comfort (Figure 1).

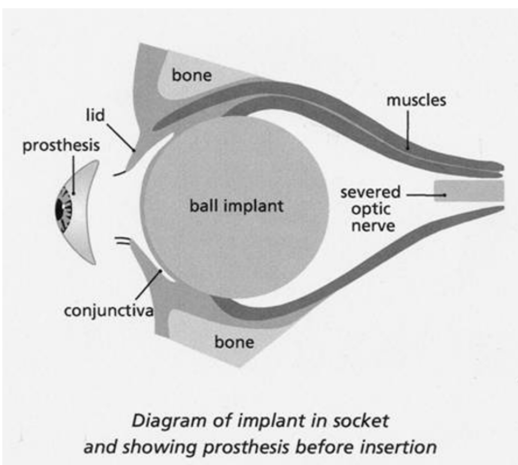

Figure 1: Prosthesis and implant

The current approach of my technical project will focus on how photogrammetry can be used to redesign the process of creating an ocular prosthesis. Currently, making the prosthesis requires painfully injecting a gelatinous material into the enucleated socket and leaving it to harden. Once hardened, the mold is used to develop a custom prosthesis. For a growing child, a new prosthesis is required at a minimum every year; general anesthesia is sometimes necessary during the gel injection. The complete process requires many clinical visits and an expensive price tag. (Sethi et al., 2014). In contrast, photogrammetry is a non-contact imaging method which allows users to recreate 3D surfaces and generate high-resolution mesh models, which can be used to 3D print a custom ocular prosthesis. The method is low cost and easy to understand, which will be described in greater detail in the technical project.

However, socio-technical complications must be considered. Ocular prosthetics selectively advantage patients able to afford high prices and with sufficient time to attend numerous appointments. These problems reinforce the power dynamic between different socioeconomic classes in the United States since patients willing to pay are able to reap the benefits of concealing their disability, while others are not. The alternative for individuals unable to pay is a stock prosthesis, which are available at $15 and do not require an extensive fitting process. Aside from the aesthetic benefits, there is a greater risk of medical complications with stock prostheses due to a collection of socket secretion between the backing of the prosthesis and the contours of the socket as a result of the imperfect fit. Comparatively, the price of a custom prosthetic ranges between $1,800 and $8,500 (Collins, 2019). I will perform a case study of the Artificial Eye Clinic, an ocularist clinic serving the Charlottesville area (*Artificial Eye Clinic | Michael O. Hughes, Ocularist*, n.d.). Their specific pricing and fitting times will be discussed, as well as the quality of their custom prosthetics as compared to stock.

Consequently, neglecting to consider both the social and technical aspects of the project would result in a design that may not address the inequalities in treatment. Without adequate effort to minimize the costs of photogrammetry, the new design will continue to marginalize individuals unable to pay. The psychological effects of having a well-fitted, aesthetically pleasing prosthesis could be far-ranging. Furthermore, since ocularists are rare craftsmen, few practice today; only six ocularists work in the state of Virginia (*American Society of Ocularists -*

Search by State/Province, n.d.). Both the ability to travel and pay disproportionately affect patients of low socioeconomic status.

The broader goal of creating a process that will reduce cost, discomfort, and time can only be achieved if careful attention is paid to socio-technical factors. Such factors are relevant to the specific case study of the Artificial Eye Clinic, due to their high pricing, use of the hydrocolloid gel method, and time-consuming process. The proposed technical work will deliver a method of creating an ocular prosthesis that is both custom-fitted and accessible to any person wishing to receive one. Photogrammetry has minimal associated costs, is painless, and significantly faster than the current method.

Technical Research Problem

Using 3D reconstruction technology, this project will attempt to address the problems with the current design approach by developing a more efficient, cheaper, and painless technique to create an ocular prosthesis. Today, in order to obtain topographical information about the empty socket such as the volume of the cavity and fornixes, hydrocolloid impression materials are used in the socket via injection until the eyelids lift to their normal position while aligned to the gaze direction. The procedure resembles the process of creating dental impressions. Eventually, an ocularist will cast the prosthetic in acrylic. The intricacies of the iris coloring and veins of the sclera are added using hand painting. However, this process is flawed because it is highly inefficient, resulting in wasting many resources. It also requires specialized skills and is inaccessible to many patients due to shortages in craftsmen. The consequence of continuing to employ the current process is a drastic loss of time and money. More importantly, enduring pain for patients is a cost of using today's method.

Therefore, this project will attempt to replace the current method by using photogrammetry to obtain surface and volume data. First, mesh models of both the anophthalmic (without an eye) and ophthalmic sockets will be generated. Then, using image analysis, the size and shape of the prosthetic will be determined by subtracting the volume of the anophthalmic socket from the volume of the ophthalmic socket. The model will then be modified and 3D printed using resin-based stereolithography.

Photogrammetry uses 2D images to obtain geographical information about points of interest. Practically, photogrammetry can be used to generate 3D models from photos and has wide-ranging applications from mapping aerial views of sites for industrial projects to obtaining close range 3D models (Lussu & Marini, 2020). Since photogrammetry is the basis of my fabrication technique, its computational process is important to understand. After I obtain an image set and input it into a photogrammetry software, the software aligns the images by tracking points based on surrounding light intensity. The software will use an ellipse identifying algorithm to align the photos automatically. Once the images are aligned, the software uses triangulation to pinpoint the location of each point. Triangulation uses the intersection of two lines of sight from different camera angles to determine the location of a single point in space (Figure 2) (Hartley & Sturm, 1997). Space resection is used to find the precise position and angle of each camera (Helfrick et al., 2011).

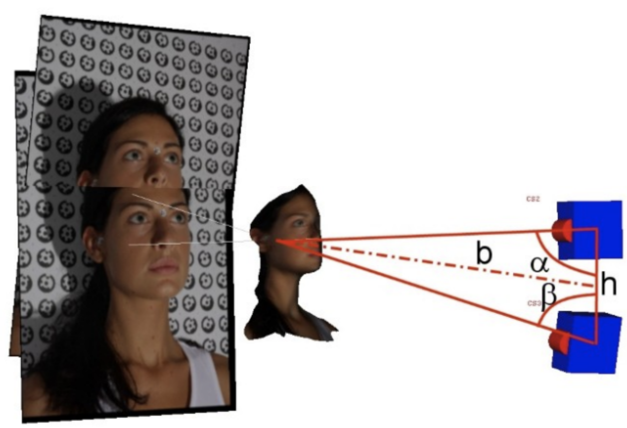

Figure 2: Triangulation model for photogrammetry

I chose photogrammetry over other imaging techniques because of its ability to generate effective 3D models using a non-contact method and without expensive resources. Compared to similar imaging techniques such as structured light that require software that may amount to thousands of dollars, photogrammetry can be performed with a modern cell phone and freeware, making it easiest to implement. Photogrammetry also does not expose the patient to harmful radiation. Other research groups have used cone beam computed tomography (CBCT) to image the socket, but this technique is non-ideal because of the health risks of radiation exposure (Ruiters et al., 2021). Additionally, advanced photogrammetry software is capable of subtracting volume elements from different models, making it ideal for developing an ocular prosthesis using the contralateral eye.

STS Research Problem

In an ideal scenario, a custom ocular prosthesis would be accessible to anyone seeking it. Because physicians recommend custom over stock prosthetics, limiting the barriers to obtaining a prosthesis will not only have psychological benefits, but also improve health outcomes due to reduced chance of infection. The current standard of care requires patients spend thousands of dollars and spare lots of free time. For some, this may not be feasible. Through the lens of technological politics, this project will examine the social and economic factors that are relevant to the success of this technology in the real world. Although numerous workshops for ocular prosthetics exist, the focus will be narrowed in on the Artificial Eye Clinic, based in Vienna, Virginia, but serving the Charlottesville area through a satellite workshop at UVA hospital.

An ocular prosthesis covers the exposed tissue after an individual undergoes enucleation, serving two functions: improving aesthetics and protecting the socket. Many conditions can lead to enucleation, the top three being tumors (33.8%), phthisis (collapsed eye structure due to trauma or infection) (16.7%), and glaucoma (16.0%). As such, obtaining an ocular prosthesis is not an isolated medical treatment. Rather, patients likely are in the midst of multiple treatments when a prosthesis becomes necessary. Additionally, in 53% of enucleations, patients are less than 30 years old (Günalp et al., 1997). Therefore, for relatively young, ill patients, an accessible and affordable prosthesis is imperative.

Drawing on technology politics, I argue that the current design method shapes power relations by privileging those willing to pay and marginalizing those who are not. Technological politics, described by Langdon Winner, asserts that technologies shape and reflect power and privilege (Winner, 1980). The quality and function of an ocular prosthesis varies depending on ability to pay, further solidifying barriers to healthcare for individuals of lower socioeconomic status. The Artificial Eye Clinic is not different from other ocularists in this regard. In order to obtain a prosthetic, their prices oscillate around $1500, after coverage from insurance. The manufacturing time is four clinical visits, spaced out depending on availability. Once the process is complete, the resulting prosthetic eye closely resembles the contralateral eye (Figure 3).

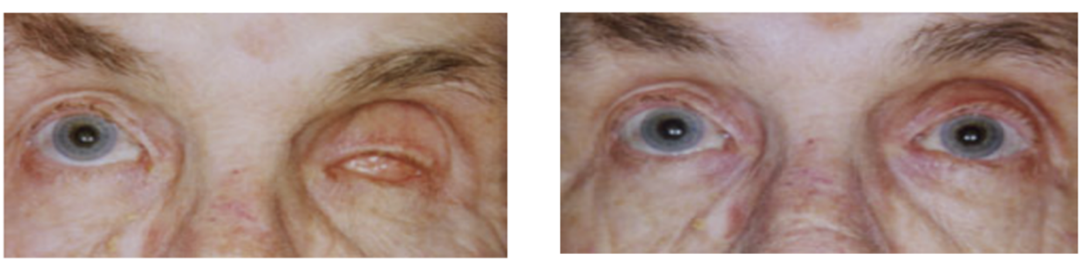

Figure 3: Custom prosthesis before and after from the Artificial Eye Clinic

Alternatively, there is a stark contrast between the prosthetics offered by the Artificial Eye Clinic and a custom prosthetic. A stock prosthesis, pales in comparison to the superior appearance and size accuracy of the custom (Figure 4).

Figure 4: Stock ocular prosthesis

Currently, ocular prostheses divide groups based on socioeconomic status. In this project, I will use firsthand experiences to highlight the struggles of obtaining a custom prosthesis. I will use studies showing the benefits of custom prosthetics over their stock counterparts, as well as the psychological aspect of regaining normal facial appearance, especially in the formative years. Additionally, it will be important to include studies on the ways individuals with visible disabilities are marginalized in society, since obtaining a superior prosthetic allows individuals to essentially hide their disability better than others. If ocular prosthetics continue to be designed using the current method, the power dynamic between socioeconomic classes will prevail. Correcting this issue will allow all patients to have the opportunity to reobtain their desired appearance.

Conclusion

In the technical and STS projects, there will be an emphasis on developing a more affordable fabrication process as well as creating equal access to prosthetics. In the technical project, using photogrammetry to obtain the topographical information necessary to create the prosthetic not only eliminates the painful impression step, but also significantly speeds up the manufacturing process and reduces the cost. Ideally, using appropriate software, a prosthetic could be made with minimal knowledge of computer science, limited financial resources, and fast processing time. Admittedly, 3D printing the prosthetic will present challenges due to access to 3D printers. However, affiliations with hospitals where enucleation is performed and subsequent research facilities will hopefully allow such access. Additionally, analyzing the Artificial Eye Clinic using technological politics in my STS research will identify and address the relevant social factors that are at play in my design process. Specifically, the power dynamic created by the unequal access to prosthetic eyes and the subsequent difficulties this causes for marginalized patients will need to be evaluated. Regaining normal facial appearance will be a major problem post-enucleation for a patient. These challenges are exacerbated with limited financial resources. Therefore, allowing equal opportunities to obtain this should be the highest priority and may be achieved using photogrammetry.

Word Count: 1,956

References

American Society of Ocularists—Search by State/Province. (n.d.). Retrieved November 1, 2021, from https://www.ocularist.org/find_ocularist_search.asp?&tab=1

Artificial Eye Clinic | Michael O. Hughes, Ocularist. (n.d.). Retrieved November 1, 2021, from https://wordpress.artificialeyeclinic.com/

Collins, D. (2019, June 16). How much does an artificial eye cost? *Oculus Prosthetics*. https://www.oculusprosthetics.com/artificial-eye-cost/

Günalp, I., Gündüz, K., & Ozkan, M. (1997). Causes of enucleation: A clinicopathological study. *European Journal of Ophthalmology*, *7*(3), 223–228.

Hartley, R. I., & Sturm, P. (1997). Triangulation. *Computer Vision and Image Understanding*, *68*(2), 146–157. https://doi.org/10.1006/cviu.1997.0547

Helfrick, M. N., Niezrecki, C., Avitabile, P., & Schmidt, T. (2011). 3D digital image correlation methods for full-field vibration measurement. *Mechanical Systems and Signal Processing*, *25*(3), 917–927. https://doi.org/10.1016/j.ymssp.2010.08.013

Lussu, P., & Marini, E. (2020). Ultra close-range digital photogrammetry in skeletal anthropology: A systematic review. *PLOS ONE*, *15*(4), e0230948. https://doi.org/10.1371/journal.pone.0230948

Moshfeghi, D. M., Moshfeghi, A. A., & Finger, P. T. (2000). Enucleation. *Survey of Ophthalmology*, *44*(4), 277–301. https://doi.org/10.1016/S0039-6257(99)00112-5

Ruiters, S., Shujaat, S., Vasconcelos, K. de F., Shaheen, E., Jacobs, R., & Mombaerts, I. (2021). Three-dimensional design of a geometric model for an ocular prosthesis in ex vivo anophthalmic socket models. *Acta Ophthalmologica*, *99*(2), 221–226. https://doi.org/10.1111/aos.14549

Sethi, T., Kheur, M., Haylock, C., & Harianawala, H. (2014). Fabrication of a Custom Ocular Prosthesis. *Middle East African Journal of Ophthalmology*, *21*(3), 271–274. https://doi.org/10.4103/0974-9233.134694

Winner, L. (1980). Do Artifacts Have Politics? *Daedalus*, *109*(1), 121–136.