Prospectus

Fabrication of an Ocular Prosthesis Using Photogrammetry

Analysis of the Technological Politics of Ocular Prosthetics

A Thesis Prospectus
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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.

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Social-Technical Problem

An estimated 5 million people worldwide wear prosthetic eyes following surgical removal (enucleation) of an eye (Pine et al., 2015). Eye enucleation is often unexpected and distressing; the most frequent cause is a traumatic injury (often work-related), followed by ocular diseases, tumors, and malformations (Modugno et al., 2013). Although ocular prosthetics do not function to restore vision, they help to restore normal appearance and aesthetics of an eye. This is important for the well-being of anophthalmic patients, as the loss of an eye is a life-changing event and can lead to depression, anxiety, and overall reduced quality of life (Rokohl et al., 2020). While there are mass produced generic (stock) ocular prosthetics, custom-made ocular prosthetics are preferable due to their patient specificity, which offers improved aesthetic appearance (Figure 1) and comfort (Chao, n.d.).

Figure 1 - Stock (top) vs. Custom (bottom) prosthetic eye (Chao, n.d.)

Although they are preferred to stock prostheses, current custom ocular prosthetics have limited accessibility for both patients and the ocularists who create them. The low number of practicing ocularists also limits the number of prostheses that can be made, as the creation of a custom ocular prosthesis requires a large amount of resources and time. The mold cast process used to obtain the shape of the patient's eye is also invasive and incredibly uncomfortable. To address the disadvantages of current custom ocular prosthesis design, I will propose a new design process for fabrication of a custom ocular prosthesis, which uses photogrammetry, digital image processing, and 3D printing to reduce the resources and time needed to create a prosthesis, as well improve patient experience

While technical improvements to the creation of ocular prosthetics offer great potential benefit, it is important to consider the socioeconomic factors present during the creation and use of this technology. Factors including accessibility, cost, and required time of creation contribute to the social work of current ocular prostheses, which unintentionally limits the accessibility of the prosthetics to some users. This is an especially concerning issue considering the importance of ocular prostheses in improving patient confidence and quality of life, as well as alleviating stress in one's social and professional life (Raizada & Rani, 2007). A lack of understanding of the social work that ocular prosthetics perform will result in failure of the prosthesis to meet the needs of all its users.

To successfully redesign the process of creating a custom ocular prosthesis, both the technical and social aspects of the problem must be addressed. Below I outline a novel technical process for creating a custom ocular prosthesis that combines photogrammetry and digital image processing to reduce the required resources for production and maximize accessibility. I also use technological politics to examine the specific failures of current custom ocular prosthetics. Through this analysis, I will demonstrate how the current design of custom ocular prostheses can unintentionally privilege certain groups while marginalizing others, and why it is therefore imperative to examine the technological politics of medical devices.

Technical Problem

The first historical records of artificial eyes are from the civilizations of ancient Egypt, Babylon, and Mesopotamia (Raizada & Rani, 2007), where mummies or statues had eyes made from precious metals as art. In the 19th century, a French ocularist made the first of the commonly known 'glass eyes,' which quickly became popular in Europe and America. Interestingly, during the Second World War, glass shortages led to the use of dental acrylic in the creation of ocular prosthetics (Raizada & Rani, 2007), which is the material often used today in ocular prosthesis design. During this time, the United States Naval Dental and Medical Schools published a fabrication model for ocular prostheses made from acrylic resin (Thakkar et al., 2012). This model is the basis for most of the current ocular prosthesis fabrication techniques.

The current custom ocular prosthesis fabrication technique is based on dental procedures, which presents a number of challenges. The initial process in custom prosthesis creation involves injecting a silicone-based material into the enucleated socket to make an impression (Figure 1), which is then left to harden and later extracted (Cevik et al., 2012). This process is invasive and uncomfortable for patients, and the impression material can be traumatic for the tissue; in most cases patients have undergone enucleation surgery as soon as 1 ½ months prior (*Prosthetic Eye*, 2018). Ocularists use the impression mold to create a wax mold, which they then use to create the acrylic prosthesis. They then paint the prosthesis and modify it (smoothing, polishing) to improve its realistic appearance. The technique I propose aims to both reduce the invasiveness of this procedure as well as the number of required resources and time.

Figure 2 - Impression Technique of the Eye Socket (Cevik et al., 2012)

Other problems arise with current custom ocular prosthesis fabrication techniques through required upkeep. Adult prosthetic eyes should be replaced every 5 years, and children who are growing need to have their prosthesis examined and potentially remade every 6 months (Rokohl et al., 2020). According to a New Zealand study, the most common age group for eye loss is ages 1-9 (Pine et al., 2015), meaning a large number of the users of prosthetic eyes get theirs replaced on a regular and frequent basis. This presents a huge financial and psychological burden for the patient, and also requires repeated resource use from the ocularist. There are also many other reasons why a prosthesis would need premature replacement, such as complications that can arise from allergic reactions, conjunctivitis, bacterial infections, post-enucleation socket syndrome, and other conditions (Rokohl et al., 2020).

The novel process I propose in the fabrication of a custom ocular prosthesis combines photogrammetry, digital image processing, and 3D printing to streamline creation, reduce resource and time use, and improve patient comfort and financial burden. The final product should closely resemble or improve on that of ocular prostheses currently in use (Figure 3). The first goal of the project is to create realistic 3D mesh models of patients' enucleated and normal eyes using photogrammetry and image alignment software called Reality Capture. In this step, I will take photos of the patient's facial profile from different angles, and input them into the photogrammetry software. Photogrammetry uses the photos to make measurements between detected objects and points in the photos to create 3D geometric representations of the objects themselves (*Photogrammetry Explained: The State of Reality Capture | Engineering.Com*, n.d.). I will then input the final 3D model into CAD software, where I will compare the models of the enucleated eye and normal eye and perform volume subtraction to get the desired prosthesis shape. This step will replace the current mold cast process used to create impressions of enucleated sockets.

Figure 3 - Custom Ocular Prosthesis (Chao, n.d.)

The secondary goal of the project is to 3D print the ocular prosthesis. This will be done using resin-based stereolithography printing. Although current prostheses use acrylic, it is not possible to 3D print in acrylic with a high resolution; printing in acrylic could lead to imperfections and porosity in the device. Alternatively, there are a variety of biocompatible resins that could be used in the future to 3D print the prosthesis ("3D Printing Guide"). After printing, I will then sand and modify the prosthesis to ensure the surfaces are smooth, and compare the size and shape to pre-existing prosthetics. At this point, I would begin to refine the photogrammetry process and CAD modifications to optimize accuracy and comfort of the prosthesis size and shape. I would also acquire patient feedback on the models. The overall goal of the technical project is to redesign and improve the process of creating custom ocular prosthetics while maintaining a product that is accurate, customizable, and clinically appropriate.

STS Problem

The ocular prosthesis exists as a solution to conditions resulting in the removal of an eye, to improve the appearance of the lost eye and protect the socket from potentially foreign bodies. Improved aesthetic appearance of the lost eye is vital to improving patient quality of life. While stock ocular prostheses are a more affordable and accessible choice, custom ocular prosthetics offer much greater comfort and aesthetic appeal, and can therefore further reduce the psychological burden accompanying the loss of an eye, and prevent complications that can result in remaking of the prosthesis. While ocular prostheses have established technical functions, their design also has inherent socioeconomic repercussions. The financial burden of a custom ocular prosthesis for the patient is extreme - the cost of a custom prosthesis ranges from $2,500 - $8,300, excluding the cost of surgery for eye removal (*Prosthetic Eye*, 2018). This, in combination with how prostheses must be replaced every 5 years for older patients and every 6 months for younger patients, results in recurring financial loss over the course of a lifetime for a patient that wishes to maintain the desired appearance of their eye.

In addition, patients need to attend multiple clinic visits during the creation of the custom prosthesis, as well as check-up visits every 6 months to ensure proper fit of the prosthesis. This excludes patients with busy work or life schedules, and patients in poor health who have trouble attending regular appointments or who may experience distress as a result of the invasive fitting process. In the case of a particular geriatric patient, he was unable to obtain a custom prosthesis due to the required large number of visits to the clinic, his financial status, and general health condition, and instead used a stock prosthesis that did not fit him well (Kamble et al., 2013). If we continue to evaluate custom ocular prosthetics based only on their technical function of restoring aesthetic appeal and patient quality of life, we will miss how it also works to shape power relations by privileging some and marginalizing others. In this project, I propose that the current design of custom ocular prosthetics marginalizes certain social groups, and therefore possesses political properties that must be considered.

To support this proposal, I will be utilizing the framework of Technological Politics. This framework, outlined by Langdon Winner, states that certain technologies have political properties, and that it is important to note the characteristics of technical objects and the meaning of those characteristics. Winner argues that technological artifacts can be judged not only for their technical functions, but for the ways that they embody specific forms of power and authority. He outlines 2 main ways in which artifacts can contain political properties; I will be focusing on the first. Here, Winner describes instances in which the invention, design, or arrangement of a specific technical device or system becomes a way of settling an issue in a particular community (Winner, 1980). In these cases, the process of technological development is inherently biased, and results in the unintentional marginalization of certain social groups and the benefit of others (Winner, 1980). This interpretation suggests that it is imperative to consider all stakeholders during the process of technological development, as technological development itself can be inherently biased towards particular social groups.

I propose that the technological development of the custom ocular prosthesis is inherently biased towards particular social groups, mainly those who are young, in good health, wealthy, and with flexible work schedules, and that this bias has devastating social consequences for excluded users. To further this discussion, I will analyze specific cases of ocular prosthesis use and reasons preventing those patients from acquiring custom prostheses, as well as the social implications of this inaccessibility. These include cases where patients had stock eyes for extended periods of time resulting in damage (Kamble et al., 2013), as well as cases where patients could not obtain a prosthesis for years following enucleation (Puranik, 2013). I will also highlight other instances of medical device design where similar social groups were marginalized. Using technological politics and these case studies, I will show how it is imperative to consider all stakeholders and potential users when designing technology, and how medical device design often has inherent bias towards particular social groups. This will lead to a new interpretation of the social work of ocular prosthetics and medical devices as a whole.

Conclusion

The technical report will propose a new design technique for the fabrication of current custom ocular prosthetics. This technique prioritizes patient comfort and minimizes resource, time, and financial requirements. The end goal is to redesign the creation of custom ocular prosthetics while maintaining a similar, clinically-applicable product that is comparable to ocular prostheses currently in use. The STS research paper will seek to provide further insight into the technological politics of custom ocular prostheses and how it marginalizes certain social groups with unintended consequences, with emphasis on specific case studies.

Together, the technical and STS projects will highlight the importance of not only the technical benefits of ocular prostheses, but the social implications of their design, and how it is imperative to consider all stakeholder groups in technological development. This will address the broad socio-technical issue of inherent bias in medical device design and the steps necessary to create products that are accessible for all users.

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