Blinking Orbital Prosthesis

BME 200/300
Department of Biomedical Engineering
University of Wisconsin – Madison
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Andrew Bremer – BSAC
Padraic Casserly – Team Leader
Becca Clayman – Communicator
Katie Pollock – BWIG

Client
Greg Gion
Medical Art Prosthetics, LLC

Advisor
Mitch Tyler
Department of Biomedical Engineering

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Abstract

The goal of this project is to design and construct a blinking orbital prosthesis. While current orbital prostheses have the visual appearance of a normal eye, they are static and do not move. This makes a prosthesis quite noticeable, especially when a person blinks their normal eye – giving the appearance of constant winking. This project aims to create a blinking orbital prosthesis that will mimic the blink of a normal eye. Use of a blinking prosthesis can help disguise the prosthesis and boost the user's confidence in their appearance, which can increase their quality of life. The ultimate goal of this project is to coordinate the prosthesis's blink with that of the normal eye; however the first objective is to create a controllable single blink that mimics a normal eye.

Background and Motivation

Every year 11,000 people in the United States have an orbital exenteration – a complete removal of an eye and the tissues surrounding the eye. This can occur due to an injury or disease, such as squamous or sebaceous cell carcinoma. While sight in that eye is permanently lost, it is possible to replace the eye with a realistic prosthesis to give the user their original appearance.

Figure 1: Acrylic eye prostheses

An orbital prosthesis is made using an acrylic eye made of polymethyl methacrylate, also known as PMMA, as seen in Figure 1. The acrylic eye is set in a static silicone restoration of the soft tissues. These soft tissues include the eyelid and all of the skin surrounding the orbital cavity lost during the exenteration. This unit can then be inserted and removed on a day-by-day basis. Currently the orbital prosthesis gives the appearance of a natural eye, mimicking the skin and the glassy orbital, as seen in Figure 2. The only reason that the prosthetic eye is noticeable is because it is not animated; it does not blink. Patients of orbital exenterations with a prosthetic eye are more likely to feel self-conscious of their disability because of the prosthesis's inability to mimic the animation of a blink. Many patients wear dark glasses to cover up the prosthesis for this reason. If the prosthetic eye could blink, this would raise self confidence in prosthetic patients.

Source: Neurosurg Focus © 2002 American Association of Neurological Surgeons

Figure 2: An example of using an orbital prosthesis

This project is a continuation of a previous semester. The previous team was able to fabricate a prototype that produced a blink using a mechanism driven by a motor, as seen in Figure 3. Two prongs were attached to the back of the prosthetic eyelid. A motor powered by a battery spun an arm that made contact with the two prongs. When prong B was hit, the lid would be forced down and the eye would blink. The arm would continue to rotate and make contact with prong A, which would force the eyelid up, completing a blink. While this design does create a blink, there are several design specifications which it does not meet. First, the prongs that facilitate the movement of the eyelid stick out from

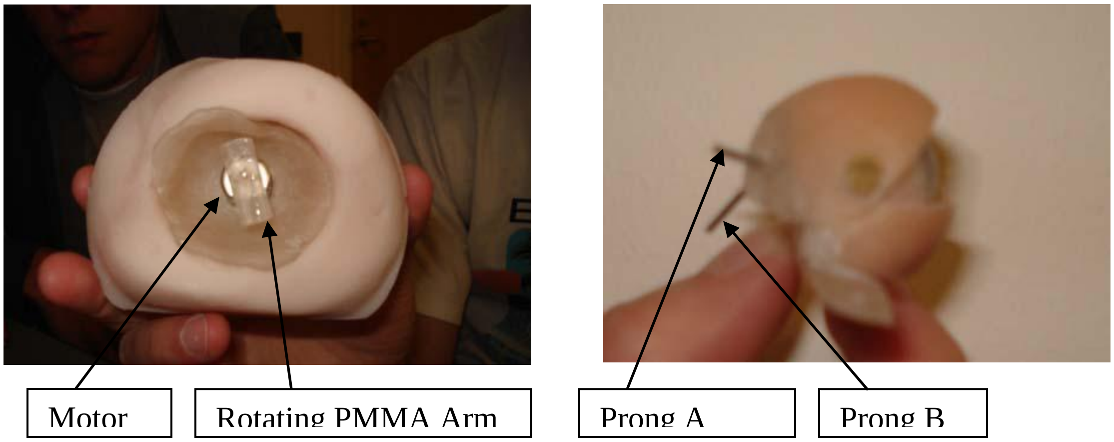

Figure 3: Prototype of previous semester’s team

the back of the prosthesis, creating a potential hazard to the patient. This also means that the mechanism is not entirely contained within the cavity – including the rotating arm and motor. Second, while the blink occurs, it does not mimic a single spontaneous blink of a normal eye – that is, it is a rapid succession of blinks. Third, the mechanism creates a lot of contact behind the eye, causing a lot of noise to be made each time the prosthesis blinks. The amount of noise produced by the prosthesis causes it to be noticed by the outside observer.

Problem Statement

When a patient has an orbital exenteration the large cavity is restored with an acrylic eye surrounded by a detailed but static silicone rubber restoration of the soft tissues (lids, etc). The PMMA eye is incorporated into the silicone part and the patient just places the entire unit in each day. It is retained with adhesive, osseointegrated percutaneous fixtures or by gentle anatomical fit. There seems to be adequate volume in a well lined cavity to house the needed mechanism for animation. The goal is to fabricate a

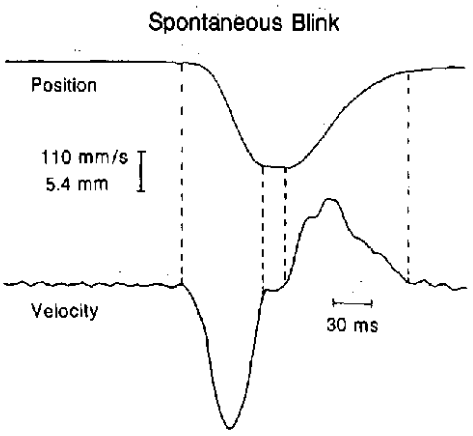

Fig. 1. Position and velocity traces for a typical large amplitude spontaneous blink. Vertical dashed lines mark the start and end for each of the down- and up-phases, respectively.

Figure 4: Graph showing velocity and position of an eyelid during blink

patient simulator model with a prosthesis that blinks and a mechanism developed that would synchronize blinking with the working eye. Figure 4 is from a paper about investigative ophthalmology and visual sciences that tracked upper eyelid movements that were measured with a search coil. The graph shows velocity and position versus time of a spontaneous blink. We need to mimic the motion of a blink; this graph shows that the motion of the upper eyelid is about the same in each direction which helped us to choose a mechanism for the prosthesis. The graph also shows that the velocity of a blink is approximately 110 millimeters per second and 1700 degrees per second. We need our mechanism to reach this velocity so that it correctly mimics the blink and speed of the natural eye.

Design Specifications

Along with the client, the team set several requirements for the design. First, the actuator mechanism needs to be self-contained within the orbital cavity. Since many people wear glasses to cover up the prosthesis, it is acceptable to have an external power source – for example, a battery contained within the glasses frame. The device should also mimic a typical spontaneous blink of a normal eye – at a velocity of approximately 1700 degrees per second. The blinks should also be controllable. The mechanism should not be noticeably audible, producing less than 15 decibels. Finally, the device should be safe to use within the orbital cavity. The client has an adequate budget for this project.

Alternative Designs

Design 1: Solenoid Actuator

The first design that our group formulated is based on a solenoid coil wrapped around a ferromagnetic core located behind the eyelid. When a current is applied to the coil, it creates a magnetic field directed upwards that is amplified by the core. The magnetic field that is produced acts on an external permanent magnet that is attached to the eyelid via an elastic or hinged connection. When the current is turned on, the external magnet is repelled upwards causing the eyelid to pivot on its hinge and close. When the current is turned off gravity will cause the eyelid to fall back down to its initial open position. A spring could also be incorporated into the design to pull the lid to its initial position.

This design has many advantages. In this configuration, the only times current need to be applied would be when the eyelid closes. This is power conservative, and would mean that for a majority of the time, no power would need to be used. This design is also space efficient and can be scaled up or down in size based on the current requirements and the size of the magnetic field that is required while still maintaining the size requirements of the project specifications.

The design does have a few drawbacks. At this time, we are unsure whether we would be synthesizing this mechanism ourselves or if we would be purchasing the solenoid mechanism. If we are creating the prototype ourselves, we may run into some problems related to the size of our current and magnetic fields. We will need to be sure to keep these low so as not to violate the safety portion of our design requirements. Depending on how large our design ends up, we will also need to determine if it is realistic to enclose the power source and its circuitry in the cavity or if it will need to be connected to an external pair of eyeglasses.

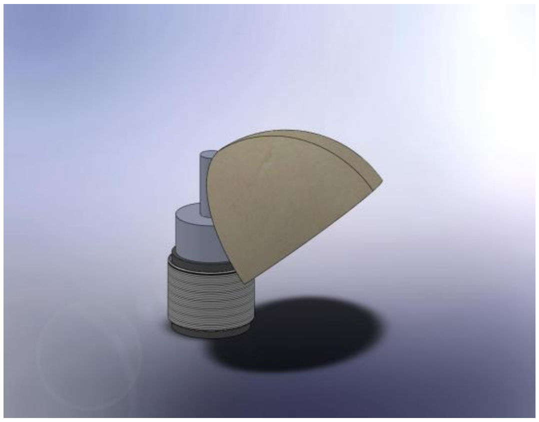

Figure 5: Solenoid open eyelid position

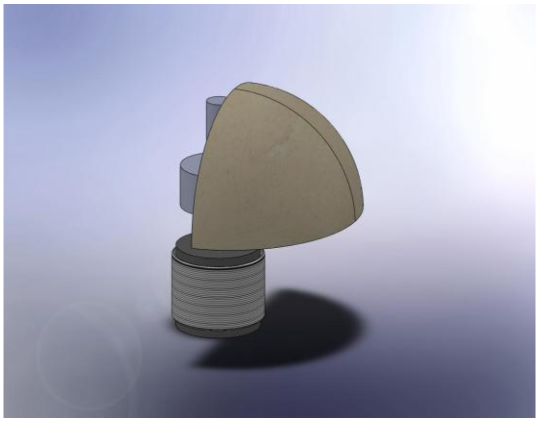

Figure 6: Solenoid closed eyelid position

Design 2: Linear Actuator

This design operates around a linear actuator located behind the eyelid. A linear actuator functions very similarly to a piston in a car engine. When a current is applied to the actuator, its piston moves rapidly up and down. This piston would be attached via an elastic or hinged connection to the rear of the eyelid much like the solenoid actuator design. When the piston of the linear actuator is extended, the rear of the eyelid will be forced up, pivoting the eyelid on its hinge causing it to close. When the piston is retracted, the eyelid will be pulled with it and it will return to its open position.

This design has a few advantages, including the construction and circuitry aspects of the design. For this design, our group would simply have to order the actuator and connect it to the eyelid; all of the circuitry that regulates the piston movement is contained in the actuator.

However, this design has several disadvantages. Since our group is not capable of constructing this kind of actuator within the given time frame, we would be forced to purchase it, which would cost almost $600. This price is also for the smallest model we could find, which still isn’t small enough to fit in the orbital cavity. These drawbacks aside, if we were able to purchase a linear actuator at a reasonable price that was dimensioned to fit in the orbital cavity, we would still have to determine exactly how much current to apply to make the eyelid open and close at normal blinking speeds in a single iteration.

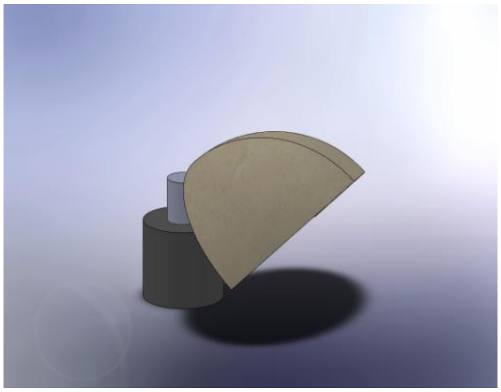

Figure 7: Linear Actuator open position

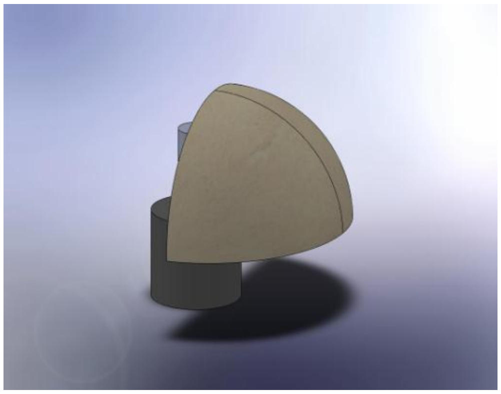

Figure 8: Linear Actuator closed position

Design 3: Belt/Motor

In our belt/motor design, the driving mechanism for movement is the motor located in the center of the base (shown in black in Figures 9 and 10 below). The base also includes four rollers and a belt that is wrapped around the motor and rollers (shown in green). When the motor moves clockwise, the belt moves in a counterclockwise direction. When the motor moves counterclockwise, the belt moves in a clockwise direction. The movement of the belt in both cases is what causes the movement of the eyelid. When the belt moves in a clockwise direction, the elastic connection that is attached to both the belt and the eyelid moves with it, causing the eyelid to pivot and close. When the belt moves in a counterclockwise direction, the elastic connection moves with it and the eyelid pivots back to its initial open position.

Perhaps the greatest advantage to this design is that we would not be limited to only two positions of the eyelid. Rather than only having an open and closed position, we could half-close the eyelid, or keep it in a half closed position to simulate exhaustion. Another advantage to this design would be the ability to control the speed of the motor more easily than we would be able to control the speed of the actuators. By controlling the speed at which the motor revolves, we can control the speed at which the eye blinks. This would allow us to accurately simulate the speed of a normal blink as well as incorporate a fast or slow blink if we want to simulate excitement or exhaustion.

Despite the advantages this design offers in controllability, this model would be extremely hard to construct. The small scale of the project makes it extremely difficult to construct a base with rollers and a belt small enough to make this design feasible. There would also need to be significant circuitry to attain the level of controllability that this design calls for, such as changing the direction and speed at which the motor operates.

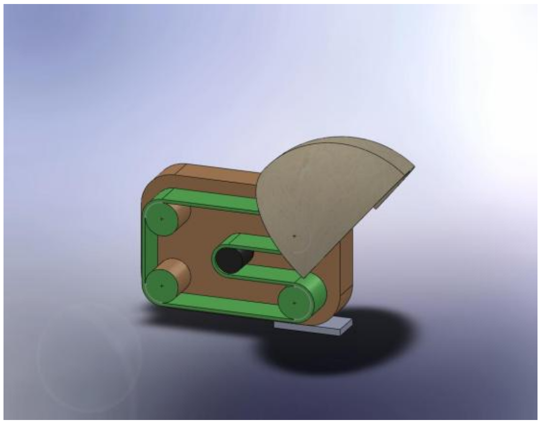

Figure 9: Belt/Motor open eyelid position

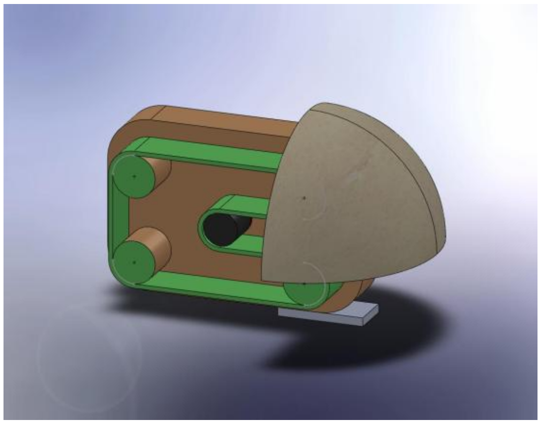

Figure 10: Belt/Motor closed eyelid position

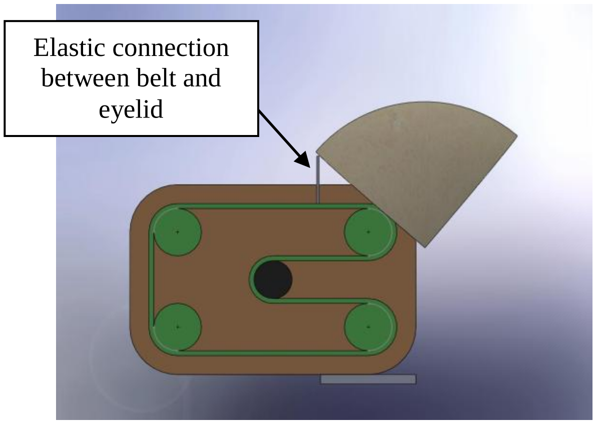

Figure 11: Belt/Motor side view. Open eyelid position shown.

Design Matrix

A design matrix was used to determine which design will be focused on for the remainder of the semester. Based on the client requirements and team goals, each design was rated in six categories. Categories were weighted, with more important criteria having a higher possible score. As seen in Table 1, the designs were rated on the level of noise produced, extent of current control, size, safety, ease of manufacturing, and cost. Noise and cost, while important considerations, were not as concerning as the other criteria. These were each weighted as 10, with the remaining categories each worth 20, making the highest possible score 100. The solenoid actuator was rated highest in the noise category because it does not use a motor, which would create noise, and it also involves the least amount of contact between parts. For control of current, the linear and solenoid actuators were rated highly since current would only need to be in one direction and turned on and off, as opposed to the belt/motor design which would require an alternating current. Preliminary research showed that a solenoid actuator could be entirely self-contained within the orbital cavity, whereas the linear actuator and belt/motor would be much more bulky and require more space, which is why the solenoid actuator was rated higher in this category. Each design is safe – there would be no exposed wires or sharp points to pose a danger to the user of the prosthetic, so each design received the same score of 15. Since there is a limited amount of time for a prototype to be built, ease of manufacturing was weighted heavily. The simplicity of the designs was considered, resulting in the linear actuator being more highly rated than the other two designs. The belt/motor design is tremendously complex, with extensive circuitry involved, which is why it did not receive a high rating in this category. While cost is a factor, we have an adequate budget, so it was not weighted very heavily. Preliminary research on costs of design parts found that the linear actuator would be quite expensive, whereas the other two not nearly as much so. The solenoid actuator received the highest total rating of the three designs, so this is the design we will continue to work on for the remainder of the semester.

Design	**Noise (10)**	**Control of Current (20)**	**Size (20)**	**Safety (20)**	**Ease of Manufacturing (20)**	**Cost (10)**	**Totals**
Solenoid Actuator	9	17	16	15	12	8	**77**
Linear Actuator	7	19	10	15	19	2	**72**
Belt/Motor	5	10	10	15	8	8	**56**

Table 1: Design Matrix

Proposed Design

The solenoid actuator has a simple mechanism with several benefits that make it the optimum design to use. The solenoid, as seen in Figures 5 and 6, is made from a coil of wire with a current passing through it. This creates a magnetic field that causes a magnet attached to the eyelid to move, creating the blink. Current only needs to be turned on and off with a simple switch. The solenoid can be manipulated to create specific magnetic fields by changing the number of loops in the coil, the core material, and also the cross-sectional area of the coil. The mechanism can also be custom made, or be purchased for a reasonable price. This design is also relatively simple so the ultimate goal of a working prototype by the end of the semester is very obtainable.

Future Work

After gathering the materials and assembling the device, testing will need to be done so that the proper current can be determined which allows the eyelid to actuate at an angular velocity specified by the design requirements – 1700 degrees per second. To find the proper current, however, a functional solenoid will have to be used. We have yet to decide whether we will construct the solenoid or purchase it. If we construct it, which would be quite inexpensive, there will be a few factors that will need to be considered: the type of metallic core, the number of loops which comprise the solenoid, and the cross sectional area of those loops. All three of these things in addition to the current affect the magnetic field created by the solenoid. This field is represented by the letter B in the equation $B = k\mu_0 nI$. After the solenoid is found and the proper current is determined, a switch will be connected to the system so that the blink can be manually prompted.

Finally, if the above goals are accomplished and time still remains in the semester, work can begin on phase two of the project: synchronization of the blink of the prototype to that of the working eye. To accomplish synchronization of the blinks, an infrared signaler and infrared sensor would be placed on a pair of glasses. The patient would wear these glasses as well as a reflective contact lens in his/her functional eye. When the patient blinks, the signal would be interrupted and effectively act as the new "switch." This switch would then prompt the prosthetic insert to blink simultaneously with patient's working eye.

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Appendix A: Product Design Specifications

Blinking Orbital Prosthesis
Client: Greg Gion
Advisor: Mitch Tyler

Team Members:
Andrew Bremer (BSAC)
Padraic Casserly (Team Leader)
Becca Clayman (Communicator)
Katie Pollock (BWIG)

Problem Statement: When a patient has an orbital exenteration the large cavity is restored with an acrylic eye surrounded by a detailed but static silicone rubber restoration of the soft tissues (lids, etc). The PMMA eye is incorporated into the silicone part and the patient just places the entire unit in each day. It is retained with adhesive, osseointegrated percutaneous fixtures or by gentle anatomical fit. There seems to be adequate volume in a well lined cavity to house the needed mechanism for animation. The goal is to fabricate a patient simulator model with prosthesis that blinks, and a mechanism developed that would synchronize blinking with the working eye.

Client Requirements:

- Actuating mechanism is self – contained
- Contained sagittally between the lacrimal and the zygomatic bone and transversely between the maxilla and frontal bone1
- Mimics a typical spontaneous blink
- Not noticeably audible (less than 15 dB)
- Safe for use within orbital cavity
- Adequate budget available

Design Requirements:

A. Physical and Operational Characteristics

1. *Performance Requirements*: Mimic a typical spontaneous blink, where a “typical spontaneous blink” is defined by a change in amplitude of the eyelid of 10-mm at a velocity between 150 mm/sec and 350 mm/sec (1700°/sec)2

2. *Safety*: Must be safely contained in orbital cavity with no exposed wires or other materials that would interfere with existing human processes and a magnetic field strength of less than 3 mG3

3. *Accuracy and Reliability*: Produce a blinking motion that is 0.16-0.4 seconds in duration when prompted

4. *Life in Service*: Functional with single power supply for a full 15-hour day

5. *Shelf life*: The device should have a shelf life of 1 year

6. *Operating Environment*: Should be able to operate within orbital cavity while exposed to fluctuating conditions within and around the human body, including temperatures between -29° and 49°C

7. *Ergonomics*: The device should be manufactured to fit comfortably within the orbital cavity.

8. *Size*: Volume of orbital cavity varies between patients so device should be as small as possible in order to fit in a range of cavities, but should be no more than 3 cm in diameter.

9. *Mass*: The device should be no more than 60 grams, but additional weight may be added if external components are included (i.e. eyeglasses).

10. *Materials*: The portion of the device in contact with the skin is primarily composed of silicone and should not cause irritation, as shouldn't the other materials comprising the device.

11. *Aesthetics, Appearance and Finish*: The device should mimic as closely as possible a normal human eye.

B. Product Characteristics

1. *Quantity*: Only one prototype required, but should have the ability to be included in custom made orbital prostheses.

2. *Target Product Cost*: Less than $2,000.

C. Miscellaneous

1. *Standards and Specifications*: FDA approval is required

2. *Customer*: Customer would like a comfortable, non-invasive device

3. *Competition*: There is little to no competition, as no current patents exist and no attempts are being made for non-invasive methods