Blinking orbital prosthesis

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Abstract

An orbital prosthesis is an artificial eye that closely mimics a person’s natural eye. Although they provide the patient with a more natural appearance, the prosthesis is easily noticed because it cannot blink. The goal of this project is to create a mechanism which allows an orbital prosthesis to blink. The two major parts include the mechanism for movement of the eyelid and the use of an infrared sensor for an automated system that relies on the movement of the naturally blinking eye. The focus of this prototype is devoted to the mechanics of the blink, and not the synchronization with the natural eye. Through designing and testing, a final design was chosen, which employs the use of a motor to open and close the eyelid.

Problem Statement

Motivation

Patients have requested that orbital prostheses impart more life-like qualities, including the ability to blink. Each year 11,000 incidents occur in the United States alone that leave patients with a large facial gap where the eye had been previously located (Lee,1998). The client alone sees 20 patients a year for an orbital prosthetic (Gion, 2008). Despite the realistic look and feel of our client’s prostheses, the current prosthesis does not blink, which reveals that the eye is not authentic.

Background

Orbital prostheses are used when a person suffers a tragic circumstance (injury or disease) that damages the eye and surrounding area beyond repair. Specifically, orbital prostheses are used to make a patient appear more normal, drawing less attention from the general public. Despite the life-like appearance, a prosthetic does not serve the same function as a healthy eye and can never be used to regain lost sight.

Client Requirements

The size of the orbital cavity is limited to approximately 16.4cm^3. In addition to limited space, the prosthesis must be able to operate at 37° C and atmospheric pressure. Most importantly, it must be safe for everyday patient use. Any external components must be small enough so future researchers can work on a complete enclosure.

Team Goals

Our goal is to design and create an actual size model of a blinking orbital prosthesis. Through testing, the average rate of a human blink will be quantified and imitated with our prototype. Due to our client's cost constraints, we need to keep the overall cost under $1000.

Competition

Currently, there is no mass-marketed model for a blinking prosthesis. Researchers have developed a way to detect a blink from the orbicularis oculi muscle on the unaffected eye (Honda, 1999). This technology, however, is very invasive due to the insertion of sensors into the body. In addition to this model, researchers have also developed a robotic eye (*Wired,* 2000). The main focus of this prototype was movement of the eyeball, rather than the blinking movement of the eyelid. In spite of this, the project incorporated external sensors to detect movement of a natural human's eyes. This particular prototype could be incorporated into future work of detecting an eye blink.

Alternative Design Descriptions

The adequate budget supplied by the client, and the fact that the only requirements were that the prosthesis fit in the cavity and be safe for use, allowed for a great deal of creativity in the design process. The initial brainstorming sessions produced several conclusions, most notably the fact that some sort of electrical impulse would be needed to make the eyelid blink. From this basic train of thought four designs were developed including closing the eyelid using an actuator, generating a repelling magnetic field to close the eyelid, producing an attracting magnetic field to keep the eyelid open, and using a memory metal circuit to close the eyelid.

Actuator movement

The first solution presented is an actuator connected to an op amp that would drive the eyelid up and down, causing a blink to occur. The op amp's input will be received from two electrodes connected to the contralateral eye muscle, with an addition electrode used as a reference, effectively creating a differential amplifier. This design has several advantages, the most notable being the fact that that it will work regardless of the environment outside the eye (i.e. in front of the face). This is important in situations like poor weather, or under certain research conditions. This solution does have several major flaws, however. First and foremost, this design is highly invasive, necessitating the electrodes to be surgically implanted into the patient's nerve, which will also require that the device be permanently implanted. Finally, the components take up large quantities of space. The largest of these is the power source, which must be located in the cavity to power the op amp. A typical op-amp requires an input of ±15 volts, which is 10 times as large as a typical button battery.

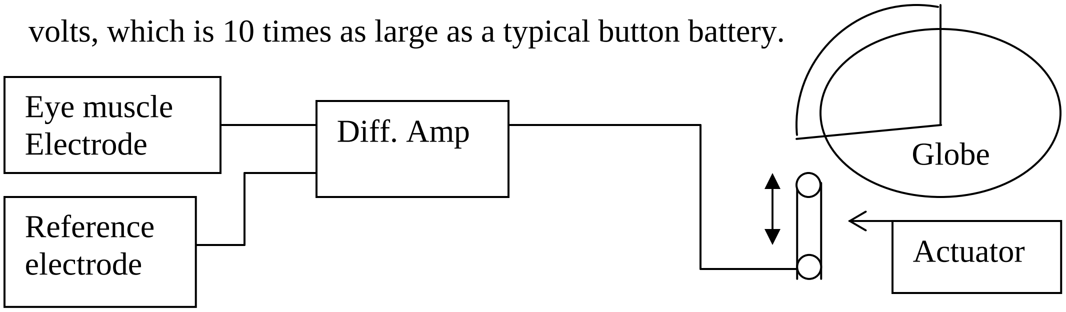


Figure 1: Block diagram of actuator design

Repelling magnetic field

The second idea offered utilizes a repelling magnetic field to close the eyelid (Figure 3). The magnetic field (often referred to as a B-field) is generated by the glasses frame in front of the prosthetic eye, located outside the cavity. The glasses use several coils of wire to effectually create a solenoid, which creates a magnetic field to repel a permanent magnetic plate. The magnetic plate is located behind the globe, connected to a compression spring that will return the plate to its initial position after the magnetic field has been turned off. The initial motion of the plate will cause the eyelid to close, while the returning motion will cause the eyelid to open back up. This design is non-intrusive, and the power source is located outside the eye cavity, allowing more space to be utilized by the mechanism. In addition, power is only required when the eye blinks, which makes the device economical and reliable.

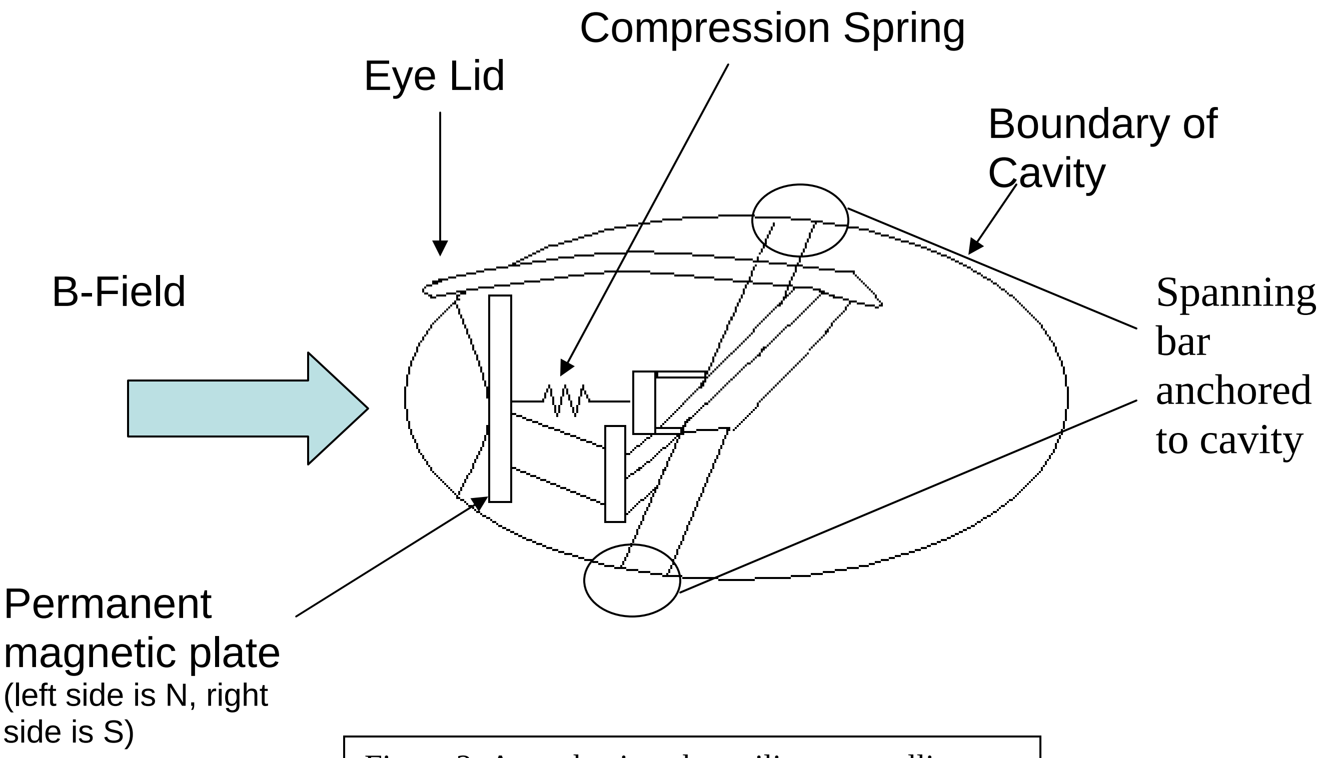


Figure 2: A mechanism that utilizes a repelling magnetic field to open and close the eyelid

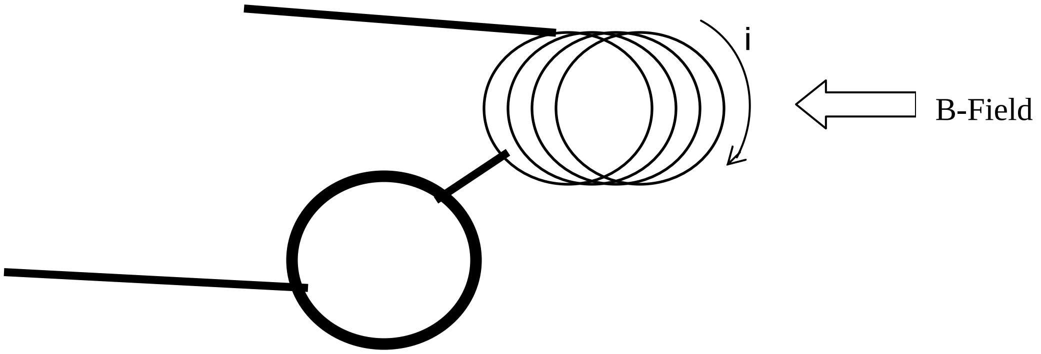


Figure 3: The glasses that produce the magnetic field as indicated. The left smaller circles represent the coils of the solenoid, with i representing the current.

Attracting magnetic field

The third idea offered is very similar to the second design, but instead uses an attractive magnetic field to keep the eyelid open (Figure 5). This design also uses the glasses to generate a magnetic field, whose direction is identical to the repelling magnetic field (Figure 4). In this design, the magnetic plate polarity is opposite that of the second design, and is connected to a tensile spring that keeps the eyelid closed. The magnetic field attracts the plate, opening the eyelid. The nature of this design necessitates that the magnetic fields default state be turned on and turned off when a blink occurs. Turning of the magnetic field causes the tensile spring to return to its unstretched length, opening the eyelid. This design has all the advantages of the previous design, and even generates a faster blink, but it has one major disadvantage. Power is being constantly consumed, necessitating that the power source be changed on a regular basis, most likely once every several hours.

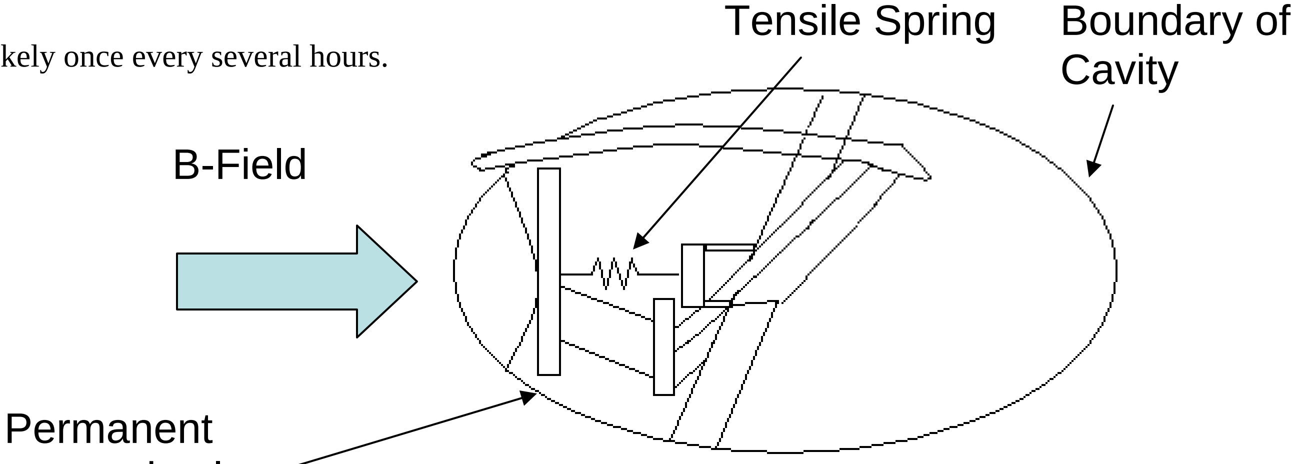


Figure 4: A mechanism that utilizes an attracting magnetic field to open and close the eyelid

Memory Metal Circuit

Initial research procured an additional design idea that involved using a memory metal circuit to initiate a blink in the eyelid. The basic concept behind memory metal, the fact that it reforms to an initial shape after heat is applied, is used in conjunction with current supplied from a power source. The memory metal's heated shape would connect to other parts of the circuit, allowing current to travel to previously inaccessible areas. Eventually, the memory metal could even be used to physically push the eyelid closed and then could relax to return it to its initial position. This design has one major advantage over all the others in that it could be designed to be very space efficient, because the memory metal can be easily collapsed into many different shapes. However, heating the wire to the point where it would cause the memory metal to return to its initial state would require a large current. The memory metal circuit would need to be entirely self- contained within the eye cavity, and as such a large current would be very dangerous. Finally, extensive circuit engineering would be required, and the time frame of the project does not allow for such a design to be developed.

Design Matrix

The design matrix includes four designs which could be used to make the orbital prosthesis blink (Table 1). These ideas include the actuator, repelling magnetic field, attracting magnetic field, and a memory metal circuit. The designs were evaluated using five criteria: "feasibility", "durability", "reliability", "cost effectiveness", and "safety". These were weighted 30%, 25%, 25%, 15%, and 5%, respectively. Due to the fact that this is a preliminary design that will not be tested on humans, safety is not a major concern of the design. The design decided upon, the repelling magnetic field, was rated highest in feasibility, reliability, cost effectiveness and safety. The repelling magnetic field was rated higher than the attracting magnetic field under reliability because it draws power only when a blink is occurring. The attracting magnetic field was rated high under durability because it uses a tensile spring, which is inherently more durable than a compression spring.

	Feasability (1-30)	Durability(1-25)	Reliability (1-25)	Cost Effectiveness (1-15)	Safety (1-5)	Total (100)
Actuator movement	15	20	22	3	3	63
Repelling B-field	25	18	20	12	3	78
Attracting B-field	25	19	18	12	3	77
Memory Metal circuit	5	10	12	8	1	35

Table 1: Design matrix that indicates the scoring of the possible designs. The highlighted design achieved the highest score, and is the proposed design.

Proposed Design

After completing the design matrix, the repelling magnetic field was determined to be the best design. This design uses a magnetic field produced from a solenoid-like electromagnet located in the glasses from in front of the prosthesis. The glasses frame, and hence the solenoid turns, are approximately 2.5 cm from the back of the globe (the part of the prosthesis mimicking the front of the eyeball). A neodymium magnet cast into a PMMA plate will be located at this position. This plate will be attached in 3 places to two separate components. The first attachment is a compression spring, which is in turn connected to a static platform. The magnetic plate is also attached to two 1cm aluminum rods, which are at a -45° angle from the horizontal, and attached to a paddle (Figure 6). This paddle is connected to the eyelid via a 1 cm connecting rod made of PMMA, which is free to rotate about the spanning bar. This rod is free to rotate around a cross bar spanning the length of the cavity.

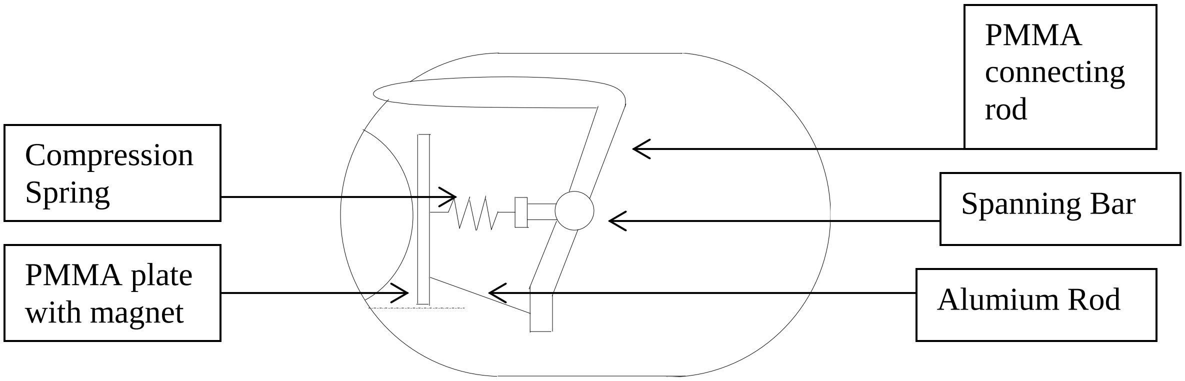


Figure 5: A side view of the mechanism allowing a blink to occur

When the magnetic field is turned on (by allowing current to flow through the wire) the magnetic plate will be forced back by a repulsive magnetic force. This motion will cause the aluminum rods to push the paddle back, causing the connecting rod to rotate around the spanning bar. This motion will force the eyelid to drop down. The first part of the blink is complete; the eyelid is now down. Once the magnetic field is turned off, the compression spring will force the magnetic plate to its former position, initiating the reverse process. The rods will be pulled back, forcing the eyelid up and completing the second part of the blink.

This design uses the maximum amount of space located in the eye cavity without overcrowding the usable space. One of its greatest advantages is that the power source is located outside the cavity, which is both safe for the patient and makes changing a full power source for a depleted one easy. This design will produce a blink, with a casual observer being completely unable to see the necessary process behind it. This design does have several possible problems, however.

The relatively large distance between the solenoid and the magnetic plate necessitates that a large magnetic field be produced in order to supply a sufficient magnetic force to push the magnetic plate back. For an N48 neodymium disc magnet, a magnetic field of more than 1.5 Teslas is required to move the disc magnet far enough to cause a blink (calculations based from magnetictherapy.com, 2008). Generating a large magnetic field means that a high current must be supplied to the coils, and large currents can be deadly. Another possible flaw is that the device will not work without the glasses. If for whatever reason the patient does not have the glasses on, the magnetic force will not reach the orbital and the blink will not occur.

Final Design

The testing the chosen design produced one major problem. Though initial data was collected with small amounts of current (.1 A), much larger values were needed to move the magnetic plate. Based on the data, it was estimated that over 10 amps of current would be required to push the magnetic plate far enough to make the eye blink. This proved far too dangerous, as even 1 Ampere of current can kill a human. This complication called for a dramatic redesigning of the entire blink system, and complete abandonment of the magnetic repulsion design in favor of a more mechanical approach.

The final design uses a high-speed motor to apply a force to the eyelid that causes it to close and open in rapid succession. The motor used is a 6VDC high speed brush motor that can perform at 20,000 rpm. The motor itself is mounted in the very back of the cavity, facing outward, fastened in place with an acrylic gel. Attached to the rotary shaft is a 1.75 cm arm made of PMMA, which rotates in the clockwise direction (when looking into the orbital). The globe/lid component has a rod attached near each end on the back of the lid, angled in opposite directions (Figures 6 & 7).

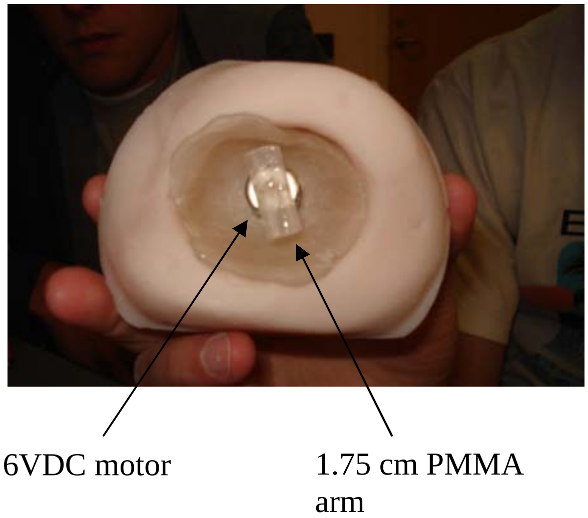


Figure 6: Motor and PMMA arm in cavity

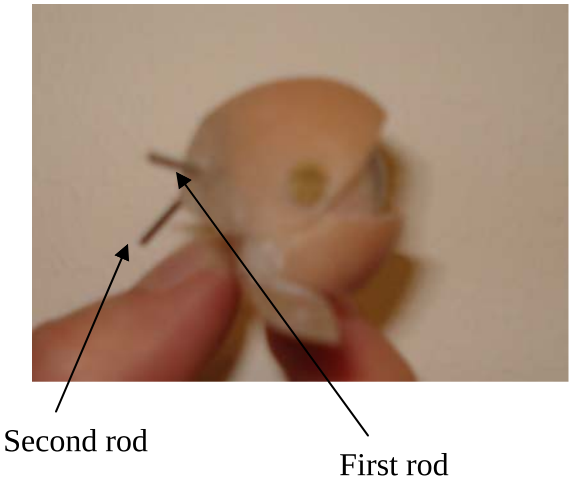


Figure 7: Prosthetic lid showing position of two rods

As the PMMA arm rotates it hits the first rod, imparting a force that will cause the lid to rotate down. This motion serves two purposes. First and most important, it will rotate the lid so that it is completely down, effecting the first half of the blink. Secondly, the rotation of the lid will cause to second rod to translate into the path of the PMMA arm. The PMMA arm will continue to rotate, hitting the second rod, which will force the lid to rotate up, completing the second half of the blink. This blink will be extremely quick, due to the fact that the two rods are only .5 revolutions apart. After completing one full revolution, the motor will be shut off via switch, ensuring that only one blink will occur.

Testing and Results

The goal of testing was to show that the prototype could not only blink, but also to show that the speed of the blink could be varied. In order to accomplish this, the prototype was hooked up to a breadboard controlled by a variable voltage supply. Using the variable voltage supply, it was possible to vary the voltage from 0 to 2 volts. Videos were taken of each test using either a 6.0-megapixel digital camera or a 1.3-megapixel MacBook iSight camera. The videos taken from the 6.0-megapixel camera were then uploaded onto a computer and edited using the iMovie program to show only the necessary parts. After this, a program called JES_Deinterlacer_v3.2.4 was used to slow down the videos to 100 milliseconds.

In preliminary testing, without the use of the globe and attached eyelid, the motor with connected arm was videotaped at 0.1V increments from 0.4 to 1.5V. From this test, the objective was to get data that described the number of arm rotations per second vs. voltage. Unfortunately, this was not feasible because it was impossible to observe the number of rotations even when the videos were slowed down. The test did, however, provide qualitative results. It was observed that the arm on the motor would only begin to rotate from a standstill if the voltage was at or above 0.8V (Table 2).

Table 2: This table shows the voltage limitation in creating enough torque to rotate the arm on the motor. Voltages at 0.8 V or above were necessary.

Voltage	Rotation at Standstill	Voltage	Rotation at Standstill
0.4	No	1.0	Yes
0.5	No	1.1	Yes
0.6	No	1.2	Yes
0.7	No	1.3	Yes
0.8	Yes	1.4	Yes
0.9	Yes	1.5	Yes

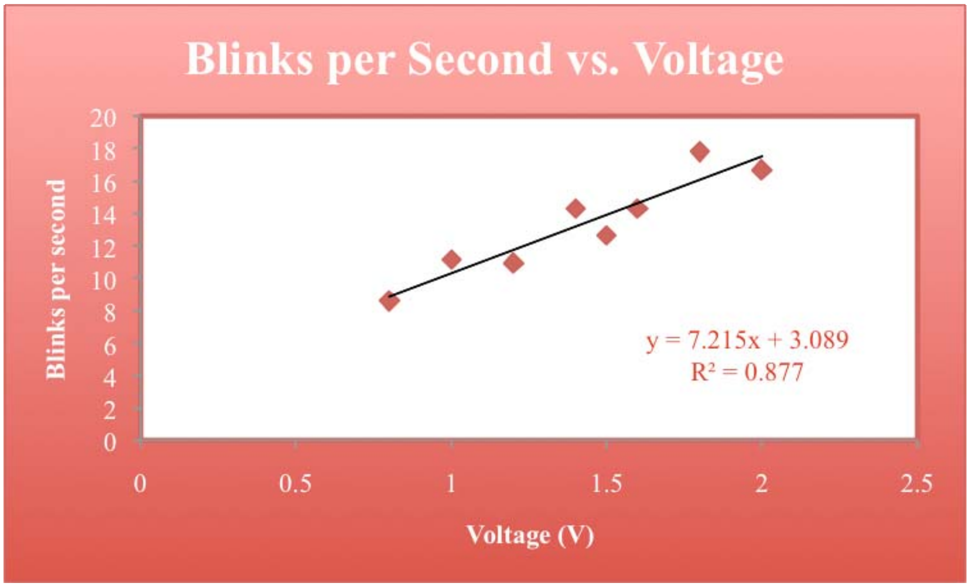
The purpose of the next test conducted was to obtain data that related the number of blinks per second to the voltage. This test included the globe with the attached eyelid. The test used voltages increasing at 0.2 increments from 0.8 to 2.0V and also included 1.5V because this matched the voltage of the AAA battery that was used when the variable voltage supply was not available. After the videos were edited and slowed down, each voltage increment was observed for time length in seconds and also for the number of blinks within that time length. Occasionally, the video would not show all of the frames and therefore not show all of the blinks. In order to get the most accurate number of blinks for that time length, a general rhythm in counting the number of blinks had to be used for each voltage (Table 2). To get the data into an easily understandable form, the number of seconds in each voltage segment had to be divided by 10 to get back into real time. Effectively, the general trend displayed a linear relationship between voltage and blinks per second. As voltage increased, the number of blinks per second also increased. From the graph, a trend line was generated

$$\mathbf{y = 7.215\ x + 3.089}$$

With x being the independent variable, voltage and y being the dependent variable, blinks per second. The linear relationship had a R^2 value of 0.877.

Table 3: This table shows the data from observing the slowed down videos. The third column shows the slowed down time already divided by 10 to make it real time and the fourth column shows the second column value divided by the third column value to give the blinks per second rate.

Voltage (V)	Number of Blinks	Seconds in Time Frame	Blinks per Second
0.8	12	1.40	8.5714
1.0	20	1.80	11.1111
1.2	24	2.20	10.9091
1.4	11	0.77	14.2857
1.5	29	2.30	12.6087
1.6	20	1.40	14.2857
1.8	13	0.73	17.8082
2.0	25	1.50	16.6667

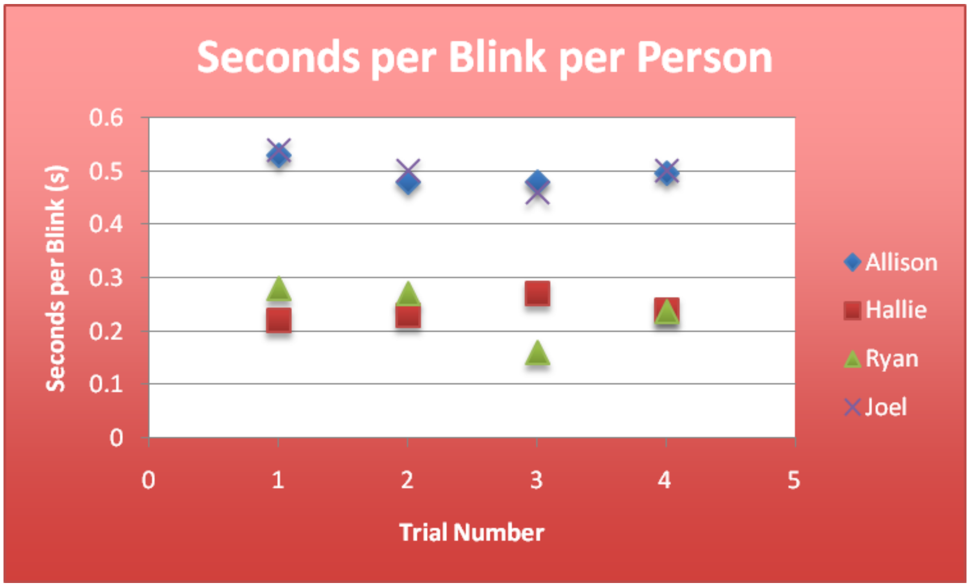


Graph 1: This graph shows the positive linear relationship between voltage and blinks per second. As voltage increases the number of blinks per second also increases.

The goal of the final test was to relate the rate of a real human blink to a necessary voltage. In other words, the objective was to find at what voltage the prototype would have to operate to mimic the average speed of a particular human. To accomplish this, each team member captured his or her normal blink using the iMovie program and iSight camera on a MacBook. After this was completed, the videos were slowed down and edited so only the blink action was part of each video clip. The amount of time for each blink was recorded for each of the 3 trials and afterward an average was taken for each person. Each value was divided by 10 to change it back into real time (Table 4). Essentially, the data qualitatively showed that each person has a different number of seconds per blink (Graph 2).

Table 4: This table shows the data from the real blink testing in real time. From the table, the average time of a blink for the team is 0.3683 seconds.

Blink Trial	Allison	Hallie	Ryan	Joel	Average per Trial
1	0.53s	0.22s	0.28s	0.54s	0.3925s
2	0.48s	0.23s	0.27s	0.50s	0.3700s
3	0.48s	0.27s	0.16s	0.46s	0.3425s
Average per Person	0.4967s	0.2400s	0.2367s	0.5000s	0.3683s



Graph 2: This graph shows the seconds per blink varies for each person. Blink trial number 4 is the average of blink trials 1, 2, and 3.

The goal of the last correlation made between the datasets was to show that because each person has a different blink rate, each person is going to require a different voltage to power their blinking orbital prosthesis. In order to relate the personalized blink to the voltage data, the seconds per blink value had to be changed into blinks per second. Taking the inverse of the seconds per blink value provided a rate in units of blinks per second (Graph 3). This value could then be inserted into the trend line created for the Blinks per Second vs. Voltage graph.

For example, Hallie's average number of blinks per second was 4.167. By making this the y-value in the equation y = 7.215 x + 3.089, x equals ~0.149V. Namely, the required voltage to power the average blink rate of Hallie would be ~0.149V. It should be pointed out, however, that the Blinks per Second vs. Voltage graph does not show data below 0.8V. This is because the arm would not rotate from a standstill at lower voltages using that motor. In order to know exactly what the necessary voltage would be for each person, a different motor with capabilities of rotating an arm at lower voltages would be required. As a team, however, we felt that even though the data from the real blinks did not fall into the range specified by the other graph, it showed that each person would require a different voltage no matter what that voltage ended up being.

Graph 3. This graph shows the the rate of blinks per second for each team member. Blink trial number 4 shows the average of blink trials 1, 2, and 3.

To improve the reliability of the testing, a high speed camera could be used to ensure every frame was captured and therefore every blink accounted for. More data should be collected for individual blinks and also a different motor with increased capability should be used. All in all, the testing and data showed that varying the voltage would change the rate of the blink and also that each person would require a customized voltage to power their blinking orbital prosthesis.

Conclusion and Future Work

Upon completing the work on the blinking orbital prosthesis, we completely met our goals. Our client's main concern for this project was to create a prototype that would spark interests from his patients or possibly from other companies. We were able to successfully show a realistic blink, and based on the testing, we were able to make this mechanism customizable by quantifying the exact amount of voltage required for various blink speeds. Moreover we left considerable room for future work and improvements. The components of the blinking orbital prosthesis were mostly contained within the cavity, all current parts are safe, and the cost of the materials used totaled less than $20.

Although the current prototype can successfully blink, a future team can start to develop an infrared system to coordinate the prosthetic eye with the naturally blinking eye, creating a fully automated system. One idea is that the patient would have to wear a reflective contact lens in their naturally blinking eye or reflective film coating their eyelid. Then, an infrared sensor mounted on a pair of eyeglasses would detect when the natural eye is open through this reflective contact. When the natural eye closes, the sensor would send a different signal to an infrared receiver within the pupil of the prosthetic eye. After triggered, the pupil receiver would initiate current flow to the motor, activating the blink. This infrared system would, in effect, replace the switch and completely automate the system. Another future improvement would be to minimize the noise associated with the blink. Placing foam or other materials on the end of the motor arm would help decrease the noise and help slow down the blink. Other improvements that could be made include making the eyelid blink only once and using a motor that could operate at lower voltages to more effectively mimic the blink rate of a human.

Appendix A: Product Design Specifications

Product Design Specification for BME 201 Group 19: Blinking Orbital Prosthesis

(As of May 12, 2008)

Group Members: Hallie Kreitlow, Joel Gaston, Allison McArton, and Ryan Kimmel

Function

The focus of this project is to design an animated orbital prosthesis. Currently, few attempts have been made to create a mechanism that allows the prosthesis to blink. The method previously used was running a wire from the contralateral eye muscle into the orbital prosthesis, causing the eye to blink with the contralateral impulse. Our team is to design and fabricate a model simulator with a prosthesis that blinks. The device used for animation must be small enough to fit inside the eye cavity, as well as contain all parts needed for operation.

Client Requirements

- Impart life-like quality to a variety of materials
- Thin materials to save weight and space
- Motion sensor housed in glasses to detect a blink
- Synchronization could and should be considered later
- Provided with an "adequate" budget

Design Requirements

According the client, the cavity has about 16.4 cubic centimeters, which is the volume in a well-lined cavity allotted to house the needed mechanism for animation. An acrylic eye surrounded by a detailed but static silicone rubber restoration of the soft tissues must still be able to fit inside the eye cavity. The prosthesis will be retained with adhesive, osseointegrated percutaneous fixtures, or by gentle anatomical fit. The typical orbital prosthesis is a softer medical silicone rubber about 1 to 5 Shore A hardness so as not to harm delicate thin skin lining the exoneration cavity, so we must maintain similar properties.

Patient application is not required, for the sole purpose of this project is to develop ideas that could evolve into a fully functional product. Therefore, it does not need to be aesthetically pleasing. The prosthesis must be light enough to avoid cumbersome properties. It must be able to function for an entire day, but it will be removed at night.

1. Physical and Operational Characteristics

a. Performance Requirements

The prosthesis is meant to resemble a naturally blinking eye.

b. Safety

The prosthesis must be able to be easily removed at night. The prosthesis might need to be housed in polyurethane or a similar material to protect the patient from air, rain, and other elements. Also, we need to make certain that the materials don't interfere with normal brain and organ functions.

c. Accuracy and Reliability

This device will be used daily by the patient, so it must be easily removed. It must be able to withstand normal wear and tear. It also must be removed for cleaning and comfort reasons. Finally, it must be accurate enough to resemble a naturally blinking eye.

d. Life in Service

The main factor limiting the life of this prosthesis is the battery. However, this can easily be replaced. Also, the main components related to animation will be outside of the eye cavity, so they could also be repaired.

e. Shelf Life

The client expects the product to last for 2-5 years.

f. Operating Environment

The device must be able to operate at body temperature, which is normally 37 degrees Celsius. It must also operate at atmospheric pressure.

g. Ergonomics

This device does not promote enhanced efficiency. Instead, it is merely to add realistic features to a prosthetic eye.

h. Size

The diameter of the globe will be about 25mm. The eyeglasses will be of standard size.

i. Weight

A normal globe weighs 30 grams, but the weight of this globe should exceed 60 grams. Also, with the implementation of eyeglasses with its added components should add at most 200 grams. Weight should be kept down, be if it is too heavy, it will be uncomfortable.

j. Materials

The orbital prosthesis will be made out of softer medical silicone rubber. PMMA will be used to mold the eyelid.

k. Aesthetics, Appearance, and Finish

The client does not request for the device to be aesthetically pleasing.

2. Production Characteristics

a. Quantity

Since there has never been a blinking orbital prosthesis in production, there will not be a considerable demand for them. However, if this product were to gain FDA approval, people would gain an interest in it.

b. Target Product Cost

The cost of all of the materials will total between \$500 and \$1000. Insurance wouldn’t fully cover this type of product, so the price could be up \$3000 over a basic orbital prosthesis. Therefore, the price could range from \$4000 to \$7000.

3. Miscellaneous

a. Standards and Specifications

A blinking orbital prosthesis has never gained FDA approval. Therefore, we will be working with a prototype while keeping aware of possible approval qualities.

b. Customer

The purpose of this device is to conceal any human imperfections. The customer base would include people seeking a more realistic appearance, even though this device has no major advantages over a basic non-blinking orbital prosthesis.

c. Patient-Related Concerns

Lowering material costs will make this device more affordable. Also, it must be able to withstand daily wear and tear.

d. Competition

Currently, few methods are being used to manufacture a blinking orbital prosthesis. Some companies have an interest in making robotic eyes involving infrared sensors.

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