OCULAR BOBBING COMPENSATION SYSTEM

Yucong Gu
University of Kansas
Lawrence, KS, USA

Yuchen Yan
University of Kansas
Lawrence, KS, USA

You Chen
University of Kansas
Lawrence, KS, USA

Tai Kim
University of Kansas
Lawrence, KS, USA

Faculty Advisor
Dr. Ken Fischer
University of Kansas
Lawrence, KS, USA

INTRODUCTION

The term "ocular bobbing" defines a distinctive class of abnormal, spontaneous, vertical eye movements which occur in a variety of clinical pathological settings [1]. For those ocular bobbing patients, their primary connection to the outside world depends on their vision. Besides ocular bobbing, they often have other central nervous system issues, like loss of hearing and inability to speak. Because of ocular bobbing, they are only able to read large print. Because of the involuntary eye movement, they typically communicate by a letter board or a touch screen computer. With ocular bobbing, the patients not only have limited muscular control of the eyes [2], but may also have intermittent blurred and/or double vision [3]. The inability to read small print creates many difficulties in their lives, such as being unable to read books or use a computer normally. Our goal is to help these patients to achieve a more normal vision, so that they can read books, watch TV, use a computer, and enjoy outdoor activities. At this moment, there is no device on the commercial market designed to improve the vision of patients with ocular bobbing.

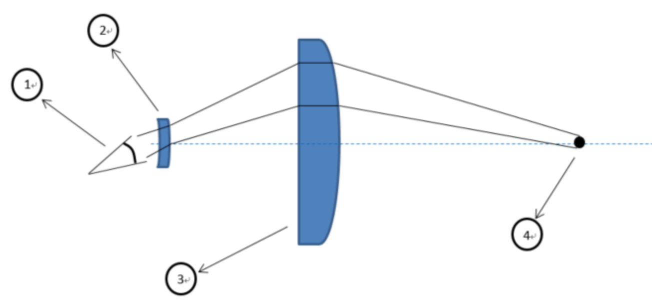


Figure 1: The schematic of the static optical compensator. The light travels from object ④ to eye ①; the path of light is changed by an aspheric lens ③, and refocused by a near-eye high-magnification lens ②

PRODUCT DESIGN

We are taking a two-pronged approach: 1) attempting to develop a static optical compensator, and 2) developing a computer vision compensation system.

The static optical compensator is designed with a specific curvature aspheric lens to refract the view in front of the subject into subject' pupil (Figure 1) regardless of their eye movement (angle of inclination). A second lens near the eye will refocus the image. The basic optical theory for this approach is refraction. When light transfers from one medium to another medium [4] [5], its direction will change due to the difference in the refraction index. The basic design includes a pair of special lenses in front of each of the patients' eyes. These lenses will refract the light from the frontal view to his pupils, no matter what angle to which his eyes have rotated. In the final arrangement, this system will be essentially like a pair of specialized glasses, with two lenses per eye. Because it is not yet certain that both redirection and focus can be simultaneously achieved, an alternate solution is also being pursued.

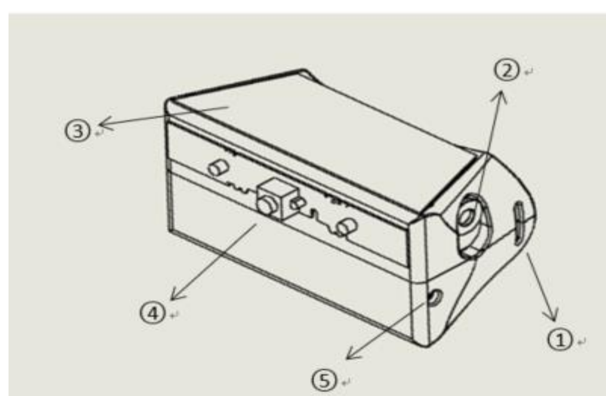


Figure 2: The Computer Vision Compensation System. ① is an attachment for the head strap, ② is the power switch, ③ is the outside case of the system, ④ is the front camera, and ⑤ is the power and communication input/output port.

The computer vision compensation system (Figure 2) utilizes a wearable display that stabilizes the front view for the subject with ocular bobbing. This system contains an eye tracking subsystem [6] and a dynamic display subsystem that moves with the eyes (Figure 3). A front camera (Logitech C920, Newark, California) captures the forward view, and sends real-time video to two small LCD displays (Fat Shark FPV, Stockholm, Sweden) in front of the user's eyes. The eye tracking system has a separate camera (Pixy, Austin, Texas) and two infrared LEDs; it tracks the user's eye movement. An Arduino UNO programmable micro controller drives a stepper motor to move the LCD displays and keep them directly in front of the eyes. The controller and battery pack will be in a remote case to reduce weight in the headset.

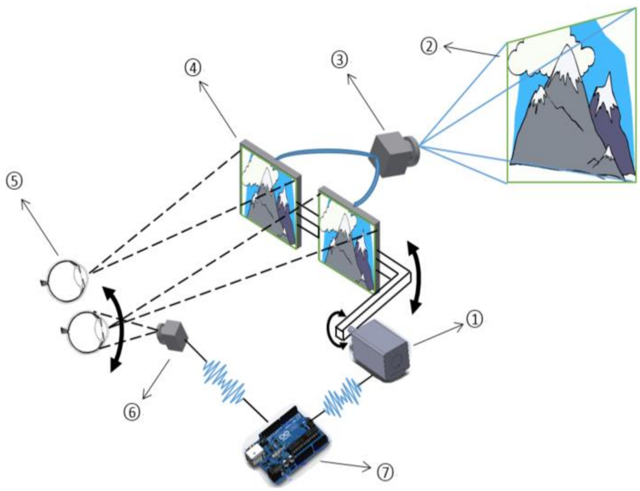


Figure 3: The schematic of the computer vision system. A front camera ③ captures the forward view ②, and sends the view to two small displays ④ in front of user's eyes ⑤. Based on the signals from the eye tracking system ⑥, the controller ⑦ drives a stepper motor ① to move the displays and keep them directly in front of the eyes.

The static lens approach is by far the superior approach if it can achieve the desired function. In terms of reliability and maintenance, there are no moving parts, batteries or electronics that could fail. In terms of aesthetics, the static lens approach provides a solution quite similar to standard eye glasses, and the subject's full face and even eyes are visible to those around him/her. However, even with optical system design software, it is not yet clear if the static lens system will be able to achieve both line of sight redirection and image clarity (focus). The computer vision system would cover the subject's eyes and likely make them self-conscious, at least as they begin to use it in public. Technically, there are challenges with this approach as well, though fundamentally the systems should work together to achieve the desired outcome.

BUDGET & MARKET ANALYSIS

The cost of the static optical compensator is currently projected to be under $1000 for all four lenses and a custom frame system to hold them. The cost of the prototype computer vision compensation system is projected to be approximately $2,000. The potential market size for this device does not appear to be large. No numbers on the condition are compiled by the Centers for Disease Control. There are only 1-2 clinical case reports of ocular bobbing in the literature each year. Thus, we estimate that there may be less than 50 new ocular bobbing patients each year in the USA. Given the very limited market, we plan to place the design(s) in the public domain, for use by individuals and non-profit groups to build, as desired, for those who need and want it. While the project does not appear to have commercialization potential, it will have a *tremendous impact* on the lives of individuals that receive an ocular bobbing compensation system, who once again have a stable field of vision.

ACKNOWLEDGEMENTS

We acknowledge grant funding from the National Science Foundation (CBET 1160130) through the University of Kansas Biomechanical Rehalailitation Engineering Advancement for Kansas (BREAK) program.

REFERENCES

[1] Mehler, M et al., *Journal of Neurology, Neurosurgery, and Psychiatry*, 51, 725-727, 1988

[2] RICHARD, R et al., *Journal of Neurology, Neurosurgery, and Psychiatry*, 44, 441-443, 1981

[3]Robert B, J. *Neurol. Neurosurg. Psychiat*, 28, 375-377, 1965

[4] Hech E et al., *Optics 4th edition*, 2001

[5] Max B et al., *Principles of Optics*, 38-39, 2003

[6] Pelz, J et al., *ETRA '04 Proceedings of the 2004 symposium on Eye tracking research & applications*, 5, 109-113, 2004

Excerpts from…

BREAK: Ocular Bobbing Compensation

Final Report

Submitted to: Dr. Ken Fischer

Project Liaison: Paul Haley

Yucong Gu | Yuchen Yan |Tai Kim | You Chen
UNIVERSITY OF KANSAS | ME 643 BIOMECHANIC DESIGN | TEAM BREAK 640

06/01/2015

Executive Summary

Grant Haley is a 27 year old male who suffered a traumatic brain injury followed by a brainstem stroke in 2010. Grant's injuries left him with a number of challenges. Grant's primary connection to the outside world at this time depends on his vision, but his eyes rhythmically bob up and down. As a result, a device to counteract this ocular bobbing problem is required.

Due to the rarity of this disorder, it has not been possible to find any off-the-shelf ocular bobbing compensator products or possible surgery solutions. Once it was concluded that there were no currently available solutions to counteract ocular bobbing, then the team began creating various designs. After engineering analysis and discussion, the team eliminated all medical and optical correction design concepts, and decided to develop a Computer Vision Compensator (CVC). The CVC utilizes a wearable display that stabilizes the front view. This system contains an Eye-Tracking Subsystem (ETS) and a Dynamic Display Subsystem that moves with the eyes. A front camera captures the forward view, and sends real-time video to two small LCD displays, in front of the user's eyes. The ETS has a separate camera and two IREDs; it tracks the user's eye movement. An Arduino programmable micro controller derives a stepper motor to move the LCD displays and keep them directly in front of the eyes. The CVC prototype met most design requirements during testing. However, ETS of CVC was not working properly. As a result, the prototype cannot be used in real life. The total cost of the project is $1633.07, which includes $101.41 for static optical correction design concepts and $1531.66 for the CVC. A new design team is requested for continuing development.

1. Introduction

Grant Haley (*Figure 1.1*) is a 27 year old male, who has ocular bobbing due to a brain stem stroke. The term "ocular bobbing" defines a distinctive class of abnormal, spontaneous, vertical eye movements which occur in a variety of clinical pathological settings (Waldman, 1965). For those ocular bobbing patients like Grant, their primary connection to the outside world depends on their vision. Besides ocular bobbing, they often have other central nervous system issues, like loss of hearing and inability to speak. Because of ocular bobbing, they are only able to read large print.

Because of the involuntary eye movement, they typically communicate by a letter board or a touch screen computer. With ocular bobbing, the patients not only have limited muscular control, but may also have intermittent blurred and/or double vision (Mehler, 1988). The inability to read small print creates many difficulties in their lives, such as being unable to read books or use a computer normally. The goal is to help these patients to achieve a more normal vision, so that they can read books, watch TV, use a computer, and enjoy outdoor activities. At this moment, there is no device on the commercial market designed to improve the vision of patients with ocular bobbing. In order to achieve the goal, the team decided to take a three-pronged approach: 1) trying to develop a medical treatment, 2) attempting to develop an optical compensator, and 3) developing a computer vision system.

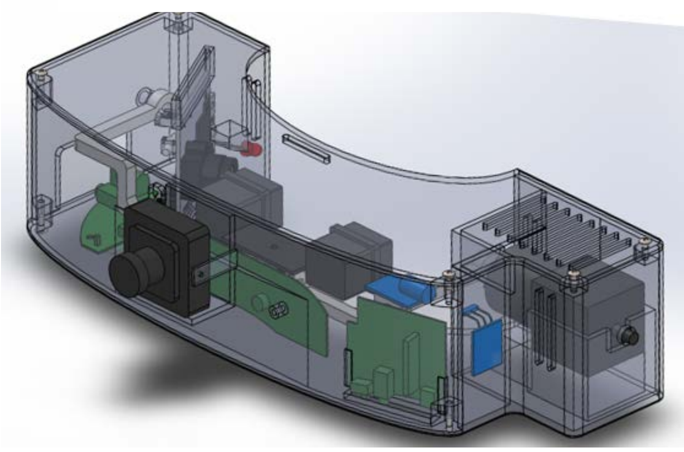
2. Background

The purpose of this design project is to compensate for Grant Haley's ocular bobbing. In order to find a way to solve the ocular bobbing problem, the team did background research on four different fields related to ocular bobbing. Those fields including symptoms/clinical cases of ocular bobbing, optic correction, computer vision aids and possible medical treatments. In the first four weeks, the team found several articles and patents from different internet databases. For example, the team found lots of information on the causes of ocular bobbing and the symptoms. Although those articles are old, they did help learn more about ocular bobbing. Furthermore, from a study (Niedermeyer, 2004), the team found a special case which is not very common but is very similar to Grant's situation.

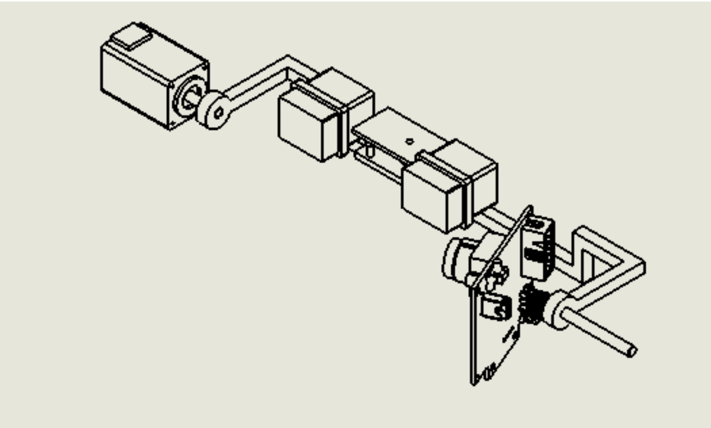
The disorder "Ocular bobbing" is a "distinctive class of abnormal spontaneous vertical eye movements which occur in a variety of clinicopathological settings" (Waldman, 1965). It is not a common disorder, and rarely happens to people (Richard, 1981). Therefore, only a very limited number of clinical cases can be found. There are only 1-2 case reports of ocular bobbing in the clinical literature each year. Likely, there are less than 50 new ocular bobbing patients each year in the USA.

5. Final Design: Computer Vision Compensator

The Computer Vision Compensator (CVC) (Figure 5.1) utilizes a wearable display that stabilizes the front view. This system (Figure 5.2) contains an eye tracking subsystem (Pelz, 2004) and a dynamic display subsystem that moves with the eyes. A front camera (Logitech C920, Newark, California) captures the forward view, and sends real-time video to two small LCD displays (Fat Shark FPV, Stockholm, Sweden) in front of the user's eyes. The eye tracking system has a separate camera (Pixy, Austin, Texas) and two infrared LEDs; it tracks the user's eye movement. An Arduino UNO programmable micro controller drives a stepper motor to move the LCD displays and keep them directly in front of the eyes. The CVC has three subsystems: Dynamic Display System, Eye-tracking System and Control System.



The Dynamic Display System (DDS) (Figure 5.4) includes two LCD displays, a LCD mounting plate, two arms and a stepper motor. The whole DDS is driven by the stepper motor. One side of the motor is mounted on the outside of the case. Another side is connected to the end of an arm. The stepper motor drives the arms to rotate around the center of Grant's eyes. The distance between pupils and LCD displays is a constant value. According to the original mounting points of the LCD, the LCD mounting plate was designed to be a small plate with three screw holes and four mounting rods. One of the three screw holes is connected to the LCD displays; the other two are connected to the two arms. The four mounting rods are used to maintain stabilization of LCD displays. A laser transmitter is attached to one of the DDS supporting arms, and a Laser sensor is fixed on the case at DDS's zero-degree point. Once the LCD display set passes the zero-degree point, the Laser transmitter will active the laser sensor, and CTS will overwrite the display position information to zero to eliminate error.



5.1 CVC Engineering Analysis

A series of engineering analysis were performed before or during the CVC design. In those analysis, the team broke the system down into basic elements. Research questions including minimum outside case size requirement, choice of stepper motor, supporting arm maximum stress and eye-tracking IRED safety issue.

DDS is the only moving parts in CVC. As a result, the factor of safety for the supporting arm is important. The goal of this analysis was to find out the maximum deflection and stress distribution in the supporting arm during operation. MSC Patran was used as FEA software. The torque applied to the supporting arm by stepper motor would be changing over time based on the stepper motor simulation data from ADAMS. The weight of the LCD display will be applied to the arm. The supporting arm is long and thin, this kind of structure might be broken easily. Furthermore, the material used to build the arm prototype is Acrylonitrile butadiene styrene (ABS), this material is not a strong martial. To conclude, the supporting arm is in "danger" of breaking, a FEA test on the arm is necessary before prototyping.

Two arms and a display holder built up the supporting arm. The Left arm is fixed on a stepper motor and it will support most of the load, so the FEA was focus on the stress and displacements on the left arm. The model of arm was created in SolidWorks and imported into Patran. The degree of freedom of this model is 16902. The arm is made from Acrylonitrile Butadiene Styrene (ABS). This material is commonly used in 3D printing.

The following properties were used in FEA.

Elastic Modulus: 4*10^5 psi

Poisson Ratio: 0.35

Flexural Strength: 1.4*10^4 psi

After applied ABS material property to the model, a solid mesh (Fig. 5.11) was applied. Based on the geometry of the left arm, the follow mesh settings were used.

Elem Shape: Tet

Mesher: TetMesh

Topology: Tet10

Global Edge Length: Automatic Calculation

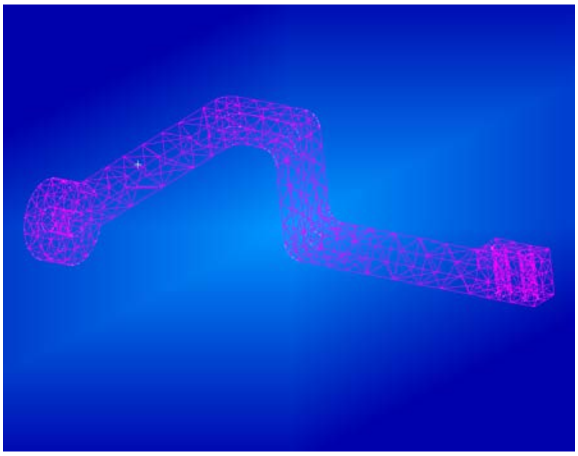


Figure 5.11: Meshed left arm, the Tet10 method with automatic calculated Global Edge Length

3 different load cases were analyzed. In all three cases, the shaft hole will always be constrained with <0, 0, 0> in displacement.

The stepper motor used in this analysis was Nema11 #1206. This motor had the maximum torque 950 g-cm (0.825 lb-in), the left side length was 1.74 in. Total load was calculated:

Furthermore, half of the LCD display’s weight is always added to the right end of the left arm. The weight of the LCD display is 38g, so a 19g (0.042lb) load was applied to the model.

In case 1, the stepper motor was not moving. The only load applied to the left arm is weight of LCD display.

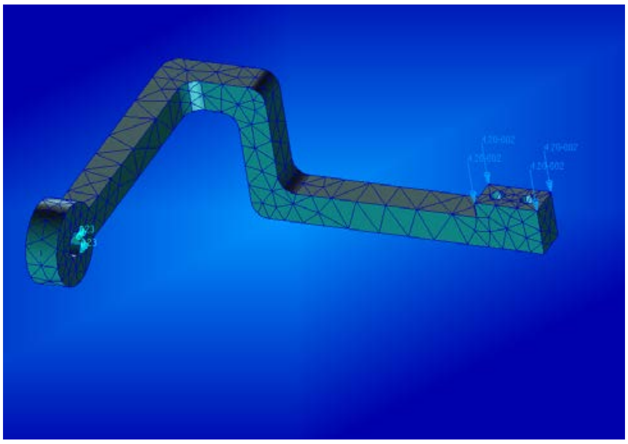


Figure 5.12: Load case 1 of left arm, the motor is in not moving

In case 2, the stepper motor would drive the arm to rotate downward from central position. In this condition, the torque applied to the arm is opposite to the LCD weight. So the total load will be

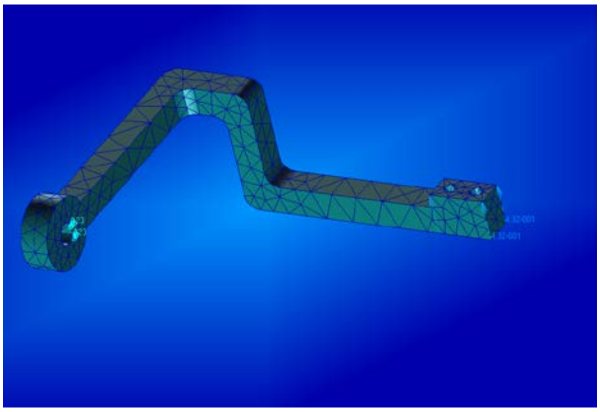


Figure 5.13: Load case 2 of left arm, the motor is moving downward from its central position

0.432 lb. upward in the surface.

In case 3, the stepper motor would drive the arm to rotate upward from central position. The total load would be the sum of LCD weight and torque load. The total load is 0.516 added to the surface.

After all three load cases were analyzed in Patran, Stress distribution plots and the displacement plots for each case were generated. In all three cases, the maximum stress occurred on the left side of the arm closed to the shaft hole (Figure 5.15). Moreover, the maximum displacement were all in the mounting surface to the LCD display holder.

The summary of the analysis is shown in Table 5.2:

None of the three load cases would cause the left arm to failure. The smallest safety of factor was 11.67, the maximum deflection is 0.0155 inch. The arm was safe during the analysis period.

CVC Hardware

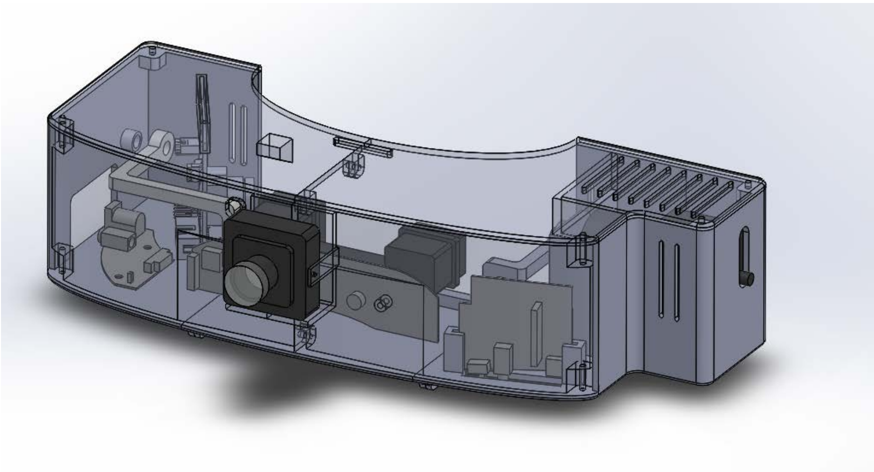


Figure 5.28: Transparent view of Computer Vision Compensator Version 3.0

The Computer Vision Compensator Version 0.2 was closed to the final product to be prototyped. But the team was not sure about whether it will work properly. So the team decided to do the 3D printing of the arms and holder at first.

When the arms and holder were printed, the team assembled the Dynamic Display Subsystem. The stepper motor is able to drive the displays to the angle as desired, but during the process it keeps jumping step by step. Then the team realized that the step size is too big of this stepper motor. The solution was to find a Nema 11 motor with front gearbox. Then the step size will decrease and the rotation will be more smoothly. After searched many website, the team decided to buy a 5:1 Gear Ratio Nema11 stepper motor.

Later, the team found some other problems when doing the testing. The stepper motor would vibrate during its operation. Moreover, the motor will transfer the heat to users' face due to its high temperature.

In order to solve those stepper motor's problem, the team did some change on the bottom case CAD. First, the left side of bottom case was extended in order to fit the new geared stepper motor. The motor will be tightly fixed and the vibration problem will be solved. Second, a wall is added to the top case to create a sealed structure of the stepper motor. Then the heat from the motor won't translate to users' face directly. In addition, more heat emission holes were add to different surface closed to the motor.

For the front camera, the team found a 700 TVL FPV camera (Figure 5.29) online. This camera has higher resolution compare to the camera used in CVC 0.2. So the team changed the CAD drawing of the front case and the new FPV camera was able to be fixed to it.

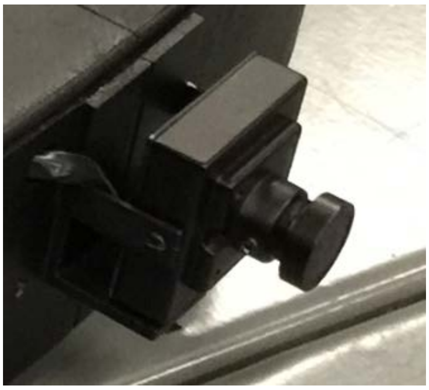


Figure 5.29: Physical Photo of FPV 700 TVL front Camera

Before doing the 3D printing of the outside cases, the team met a new problem. It was due to the 3D printer. The limitation of the printing size is 8’’ X 6’’ X 6’’. But the overall length of the case is 10.8’’. The team decided to split each case to two parts. Then add the mounting points to the split edge.

After all of these new design and CAD modification are finished. The CAD was sent to the 3D printing department. The 3D printing parts are made from ABS material and are all white color. The team assembled everything together when got the 3D printing cases.

Some new problem came up to the team when got the real case. First, one of the circuit board holder is broken during the printing because it was too thin. Second, the Stepper motor is about 0.2 in longer than the dimension from its online dimension form (When doing the 3D printing, the Geared Stepper Motor has not been delivered yet). Third, the right arm will hit one of the circuit board due to its geometry. Then some new change on the CAD was made to solve those three problems. The groove of motor was made to be longer; the circuit board holder’s wall became thicker; the right arm’s geometry was changed so it gives enough space to the circuit board. When the team got the two new 3D printing parts (left bottom case, right arm), all components were able to mount together in the wearable display.

Besides the wearable display, the team also build a control box (Figure 5.30) to place the Arduino Controller and two buttons (power button and calibration button). The control box is made from a transparent tool box. The team drilled some holes to the box to allow the wires across the control box.

Figure 5.30: Control Box Prototype. The black switch is the power switch, and the blue bottom is the calibration.

In order to makes the whole compensator has a better appearance. The team also paint the control box and all 3D printing parts to black color.

At that point, the prototype of Computer Vision Compensator Version 0.3 (Figure 5.31) was finished. The next step was test the whole system.

Figure 5.31: Computer Vision Compensator Version 3.0 Prototype. All components were set up in the device.

5.4 CVC TESTING

After the prototype was fully assembled, a number of tests were done on CVC to see if the system met the design requirements. Those tests including DDS movement accuracy test, ETS accuracy test, TV watching test, book reading test and battery life test.

The eye-tracking Pixy camera was held fixed. An infrared LED was used as a target to simulate eye movement. The target was moved to different positions simulating eye angles (-30 to +30 deg in 5 deg steps). The Pixy camera read the target position and commanded stepper motor motion to adjust the display to the corresponding angle. The actual resulting display angle was recorded. The results were shown in table 5.3, figure 5.32 and figure 5.33.

DDS Movement Accuracy Test Results

Calibration of display position	Degree of LED Light	Degree of Motor		
		trial 1	trial 2	trial 3
Up scale	30	32	28	29
	25	25	27	25
	20	20	20	18
	15	17	17	13
	10	12	10	9
	5	5	4	4
Center	0	0	0	0
Down scale	-5	-5	-5	-5
	-10	-9	-10	-10
	-15	-12	-13	-15
	-20	-17	-18	-21
	-25	-24	-24	-27
	-30	-29	-30	-32

Table 5.3: Testing result of the calibration of LCD display position

This test was designed to find out the accuracy of the eye-tracking system. In the test, the eye-tracking camera was connected to a computer, real-time eye-tracking video and eye position data were displayed on the computer. A subject was wearing the CVC and rotated his eyes to different position. All test data were recorded in table 5.4.

ETS Accuracy Test Results

	Real Eye Position	Position Shown On Computer		
		trial 1	trial 2	trial 3
Up	To the maximum	25	-35	8
Center	Look forward	2	-13	-20
down	To the maximum	-26	-25	6

Table 5.4: the accuracy testing result of eye position on a computer

Based on the results, ETS was not working acceptably, it had a very low accuracy. Due to the fact that test results were random numbers, test results were not valid. The reason of the low accuracy is Pixy camera's current algorithm works only on objects with a distinct hue. Instead of tracking the black pupil, the Pixy camera tracked the 3 white bright points on the eye shown in figure 5.34.

Due to the low accuracy, the eye-tracking system did not pass the test.

This test was designed to see if CVC can be used to read books. The distance measurement system which was used in the TV watching test was used again in this test. The setup is shown in Figure. 5.36. A print out with 11 pt. and 40 pt. Calibri font words was used.

As an electronic device, battery life is always a key factor of performance. In this test, the team tested CVC when it was running on battery mode. The team put a fully charged battery in the system, and used a stop watch to count the time until the battery ran out or system overheated. The results are shown in Table 5.5.

Battery Life Test Results

Voltage	Operating time before overheated	Operating time battery ran out
7.4 V	10 min.	N/A
5V	N/A	52 min

Table 5.5: CVC battery life under different voltage

The battery life of CVC was way below the design requirement (8hr), but acceptable in real life. Because the battery life problem can be solved by using multiple batteries or power from outlets.

A number of other problems were found during the prototype testing. Beside the ETS accuracy issue and battery life issue, the prototype also had oversize issue, overheat issue, stepper motor noise/vibration issue and durability issue. The first problem was oversize. The team found that CVC was bigger than most commercial wearable display system. Due to DDS, a big moving part inside the system, it is hard to reduce the size of CVC. The second problem was overheat. During the battery life test, the team found that if CVC ran under 7.4V, Arduino controller would overheat in about 10 minutes. Although 7.4V was under the maximum power input for Arduino, the stepper motor interface could only take 6V input. As a result, CVC could only run about 10 minutes before overheated. The solution was to step-down input voltage to 5V. Third problem was the noise and vibration. During the DDS accuracy test, the team found that the stepper motor in DDS would make some noise and vibration. Although the noise and vibration were minor, they still could be annoying. The last found problem was durability issue. The team made the outside case with a 3D printer, and used a lot of prototypical electronic parts. Those parts were not as reliable as commercial product.

8. Discussion and Conclusion

The five concept designs were based on the customer requirements, engineering specification, research and Dr. Fischer's feedbacks. Also, the final designs was determined by decision matrix and team discussion. Four of the five concept designs were eliminated due to their disadvantages after engineering analysis. CVC became the final design.

During CVC design process, the team did a lot of engineering analysis on different subsystems. Those analysis, especially software based simulation, successfully justified the CVC design. Those simulations saved a lot of time and money in the prototype and test sections.

In tests, CVC passed most tests and met most design requirement. User will be able to use the device to watch TV, read book, use computer and even go out. However, ETS of the system failed in the eye-tracking test. Because of error in eye-tracking system, CVC could not work acceptably.

Overall, this CVC design is only a partial success. Although the design concept has been proof, the prototype is not working fully functional. Future improvement in ETS is required.

9. Recommendation

At this point, the biggest problem of the CVC is the eye-tracking subsystem. Because the pixy camera cannot track black color, the ETS is not able to track user's pupil properly. The eye tracking firmware is hard to be changed. The team recommend using the Microsoft LifeCam as the eye tracking camera; and using raspberry pi or laptop as the controller. Also, there are lots of commercial eye tracking systems available. Most of them are open to third party software. The benefit of using this commercial eye-tracking system is high accuracy. The eye-tracking software for can be written with Python on raspberry pi and laptop. The team believe this is much easier than changing the firmware of pixy camera, and also more accurate than pixy camera.

The stepper motor has some accuracy and vibration issues. From the testing results, the displays can moves linearly with the IRED, but it still has some error due to the working function of stepper motor (work in steps). Even the gearbox reduced the step size of the motor, the movement is still not smooth and accuracy enough. The recommendation is using the servo motor instead of stepper motor. The servo motor can drive the object to any specific angle with very small error and vibration. So the team believe servo motor will makes the DDS works much better.

Reference

1. Waldman, R. B. D. A. A. L. (1965). "Ocular bobbing." J. Neurol. Neurosurg. Psychiat: 28, 375-377
2. Hecht, E. (2002). Optics (4th ed.). Reading, Mass.: Addison-Wesley.
3. Pelz, J. S. B. J. B. (2004). "Building a lightweight eyetracking headgear." ETRA '04 Proceedings of the 2004 symposium on Eye tracking research & applications: 5, 109-113
4. Wood, T. Stepper. Retrieved March 13, 2015, http://www.kollmorgen.com/enus/motors/stepper/
5. Klein, A. W. (2004). "Botox for the eyes and eyebrows." Dermatol Clin 22(2): 145-149, vi.
6. Rafael Fortuna, M. A. V., Aliaa Rahan Youssef, David Longino, Walter Herzog (2011). "Changes in contractile properties of muscles receiving repeat injections of botulinum toxin (Botox)." Journal of Biomechanics: 44, 39-44
7. Richard Rudick, R. S., AND THOMAS A ESKIN (1981). "Ocular bobbing in encephalitis." Journal of Neurology, Neurosurgery, and Psychiatry: 44, 441-443

8. Stone, T. About Us. Retrieved March 13, 2015, http://irlock.com/pages/press

9. Mehler, M. F. (1988). "The clinical spectrum of ocular bobbing and ocular dipping." Journal of Neurology, Neurosurgery, and Psychiatry: 51, 725-727

10. Shinjiro Kawato, N. T. (2004). "Detection and tracking of eyes for gaze-camera control." Image and Vision Computing: US 5594573 A1

11. Chen Yuliang, Tang. He. (2009). Eyeball motion simulation mechanism. China's State Intellectual Property Office: 8. CN 101711922 B

12. Kenichi Kawagoe, S.-s. (2011). LIQUID CRYSTAL SHUTTER GLASSES. United States MJ LABORATORY JAPAN CO,. LTD. US 2011/0310318 A1

13. Sliney, D.,Wolbarst, M. (1980). Safety with Lasers and Other Optical Sources, New York: Plenum Press, p.147.

14. ICNIRP Guidlines, (2000). Light-Emitting Diodes (LEDS) and Laser Diodes: Implications for Hazard Assessment.Health PhysicsVol. 78,6, 744-752.

15. Kong, X. Z. (2012). SY20STH30-0604A stepper motor datasheet. Retrieved from https://www.pololu.com/file/0J635/SY20STH30-0604A.pdf

16. Kong, X. Z. (2012). SY28STH32-0674A stepper motor datasheet. Retrieved from https://www.pololu.com/file/0J686/SY28STH32-0674A.pdf

17. Kong, X. Z. (2012). SY28STH45-0674A stepper motor datasheet. Retrieved from https://www.pololu.com/file/0J687/SY28STH45-0674A.pdf

18. n.a. (2004). OED-EL-1L2 IRED datasheet. Retrieved from https://cdn.shopify.com/s/files/1/0599/7905/files/OED-EL-1L2.pdf?324

19. Niedermeyer E. and da Silva F.L. (2004). Electroencephalography: Basic Principles, Clinical Applications, and Related Fields. Lippincot Williams & Wilkins. ISBN0-7817-5126-8

20. Wu, C. (2014). Category: 3d Printing. Retrieved May 30, 2015, from http://www.teamctrlaltdelete.com/roboblog/category/3d printing

21. Hecht, Eugene (2002). . San Francisco Etc.: Pearson, ISBN-10- 0805385665

22. Michael Plöchl, J. P. O. a. P. K. (2012). "Combining EEG and eye tracking: identification, characterization, and correction of eye movement artifacts in electroencephalographic data." Frontiers in Human Neuroscience: 9(6), 1-23

23. MCS software (2012), “Adams Tutorial Kit for Mechanical Engineering Courses SECOND EDITION”

24. da Silva F.L. (2004). Electroencephalography: Basic Principles, Clinical Applications, and Related Fields. Lippincot Williams & Wilkins.

25. Cunningham. (2011). Vaughan & Asbury's General Ophthalmology.(18th ed.). New York: McGraw-Hill Medical

Appendix – Flow chat of the computer vision system