Accommodation Glasses

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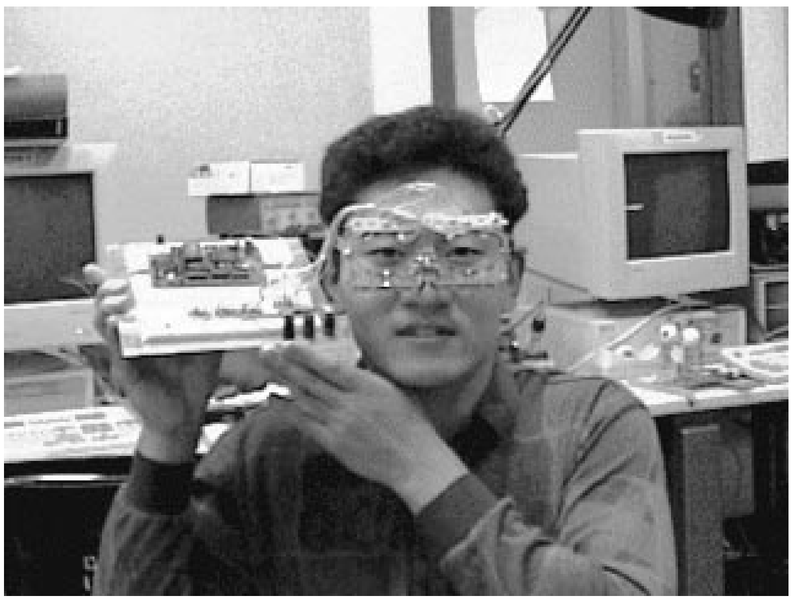

Abstract

Human eyes focus on objects with changes in vergence, the position of the eyes, and accommodation, the thickness of lens. Since many vision problems involve errors in accommodation, a change in focal power of the lens corrects the problem. Due to the close relationship between two features, one can approximate changes in accommodation from measuring vergence. The project uses this idea to enable aq pair of glasses to vary its focal power. Special sensors on the glasses track the movement of the eyes. Then the microprocessor calculates the vergence using the amplified signals from the sensors. With calculated changes in vergence, actuators move make necessary adjustments on the lens. MPEG movie of the glasses and the report is available over the internet via WWW address; http://po.eecs.berkeley.edu/~ee192 and my own WWW address; http://http.cs.berkeley.edu/~youngc.

1 Background

Implementation of automatic accommodation glasses requires background research in important features of the human eye and available technology for the robotics glasses. This section describe the features of vision that are critical in development of the device. Then it inspects the technology available today implementing auto-focusing glasses.

1.1 Vision

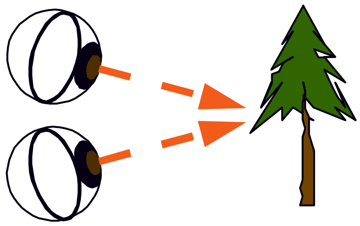

Figure 1a: Eyes focusing on a close object; Eyes move to converge on an object, crossing their visual paths. The lens flexes to form a thick convex lens shortening the focal length.

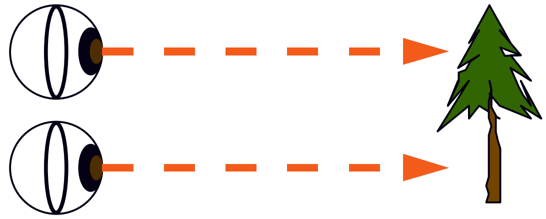

Figure 1b: Eyes focusing on an object far away; The visual paths of the eyes become parallel to each other when looking at an object beyond approximately 2 meters. The lenses become flat and relax to have infinite focal length.

There are two important features of the eyes that work together to focus an image on the optical nerve. Vergence is a feature that describes the position of the eyes, whereas accommodation is a change in thickness of the ocular lens.

As seen in figure 1, both features of the eyes work together to focus on an object. When the eyes are focusing on an object close, their visual paths converge to a point like shown on figure 1a; simultaneously the lenses in each eye become thicker to shorten the focal lengths. On the other hand, when the eyes are focusing on an object far away, their visual paths become parallel to each other. This happens in human eyes when an object is more than about two meters away. Beyond two meters, lenses in the eyes go into a state called accommodative relief. Relaxed lenses become flat to have infinite focal length.

1.2 Technology

Many industries are making many investments to make things smaller. Microprocessor industry is one of the leading industries. Every day, computers are getting smaller, allowing many products to adopt intelligence without changing much of their appearance. The growing industry in miniature motors and actuators will allow mechanisms on the products to move.

When devices become smaller, power necessary to run them also decreases. Therefore addition of these miniature devices on any sort of tools would be practical in terms of power consumption. Like microprocessors, mass production of these devices will also lower the price. Then these additions of intelligence and muscle on precise products such as glasses would be almost hard not to implement.

This idea of using this emerging technology to fix errors in features of the eyes became the basis of the accommodation lens project.

2 Problem

Most people wear glasses because of the error in the focal features of the eyes. This section discusses a few major causes of visual problems. Then a new idea to use an intelligent system proposes to universally solve the problem.

2.1 Cause

One of main reason for glasses is to correct the error in the focal length of the lens. Due to heredity, each individual has a certain eye size. The range of accommodation can be misaligned with the eyes. This causes the effect of near-sightedness or far-sightedness. The glasses are used to re-align this error, so the eyes can focus throughout the range.

Another main reason for glasses is inevitable for anyone. From the age of two to sixty, people progressively lose the accommodative feature of their eyes. For most people, the lens will stop accommodating. Thus the lens in a state of accommodative relief has an infinite focal length. Therefore people need to wear convex lens to see close images.

Today, glasses are made to correct the problems by giving each an immediate solution. Therefore glasses are all made differently even if the problems occur from the same part of the eyes. This inconvenience gave interest to an idea of universal glasses.

2.2 Idea

The idea behind the project is making universal glasses. After reading papers and talking to leading authority in this area, Dr. Lawrence Stark, a close relationship between vergence and accommodation was found.

Since a viewed object could be along the visual path of an eye, distance between the eye and the object is not possible to determine. Vergence of both eyes, however, can be used to calculate the distance.

The object should be at the crossing point of the visual paths of the eyes. When the eyes are focusing on something beyond the accommodative range, the only important factor would be to keep track of the vergence of the eyes. This idea led to materialization of the accommodation glasses.

3 Project

The glasses are divided into many parts. First, the sensors collect the information from the eyes. Then the processor takes the signals as its input. The program running on the processor, then, calculates the position of the eyes. The control signals are produced and then fed into the actuators to move the lens.

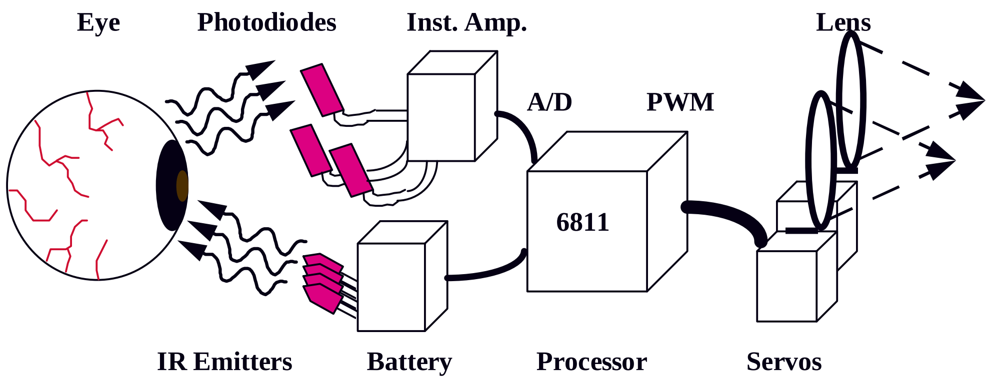

Figure 2: Sensors are used to collect intensity information. Then the differential signals are amplified using the instrumentation amplifiers. The amplified signals are then converted to corresponding digital signals. The digital numbers are used in the processor to determine the positions of the eyes using the software algorithm. Once the position is determined, the actuators are controlled by the processor to make necessary adjustments to the lens.

3.1 Sensors

Sensors to measure the movement of the eyes need to be accurate. Obtaining precise measurement is a critical part of the project.

One type of sensor that can be used is an Electro-oculo-gram. These sensors can detect the muscular activities of the eyes. Then the signals would be amplified and filtered to give precise position of the eyes. Even though these sensors are available, they tend to be expensive.

Another type of sensor uses the behavior of light. Parts of the eyes that can be seen are in different color. Pupils in the center tend to be darker than the outer parts of an eye. Therefore reflecting visual light or near infrared light on different parts of the eyes would result in reflected light with different intensities. In the prototype the light sensors are used, since they are easier to implement.

Many experiments with the sensors confirmed the intensity differences of the reflected light, in this case near infrared light. Although near infrared light gave rather precise intensity measurements, other light sources became noise to the signal. So in addition to two photodiodes keeping track of the eye movement, a third photodiode received the constant stream of near infrared light reflected off the eye. This third photodiode became the base intensity measurement of the other two.

3.2 Signals

Since the intensity measurements were small, the signals were amplified. Then the amplified signals were converted to a digital number to be fed into the processor. The voltage measurements from each photodiode ranged from approximately 290 to 305 mV(range of 15mV). On the other hand, the required intensity for analog to digital(A/D) conversion ranged from 0 to 5 volts.

Amplifying intensities directly gave very small resolution to the movement. Thus, only the reflected light from the infrared emitters was necessary. The base measurement taken from the third photodiode was use to filter out the noise intensity.

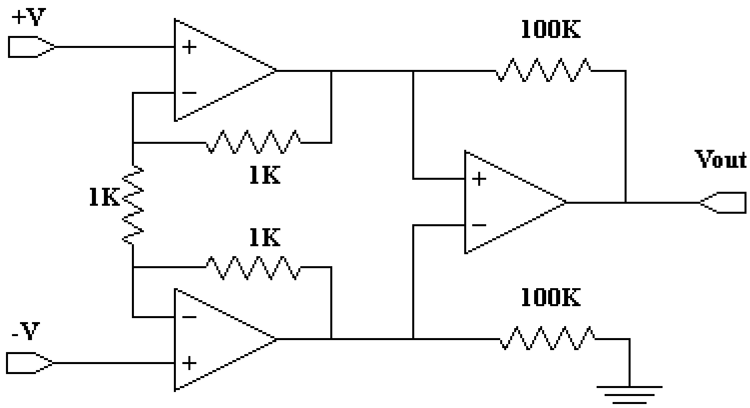

Figure 3: Instrumentation Amplifier. It is used to amplify only the differential voltage. For the prototype, three single side op-amps (0 to +30 volt) were used to build each instrumentation amplifier.

Using separate operational amplifiers for each signal could not be possible. The magnitude signal after the amplification was too large. This was because the difference of voltage needed to be in the range of 0 to 5 volts, but to get such magnitude, signals were amplified 300 times. Therefore instrumental amplifier as seen on figure 3 only amplified the difference. Amplification with figure 3 circuit was about 300 times.

3.3 Microprocessor

The amplified signals between the range of 0 to 5 V were fed into the Motorola 6811 microprocessor. Since this microprocessor could convert four analog signals to a digital number at the same time, all converters were used. Since the processor is an eight bit processor, the number generated ranged from 0 to 256.

The numbers generated from the intensity of two photodiodes per eye (figure 4) became the key values in the algorithms to determine the vergence. Many algorithms were tested. The one used in the current project was the most simple algorithm.

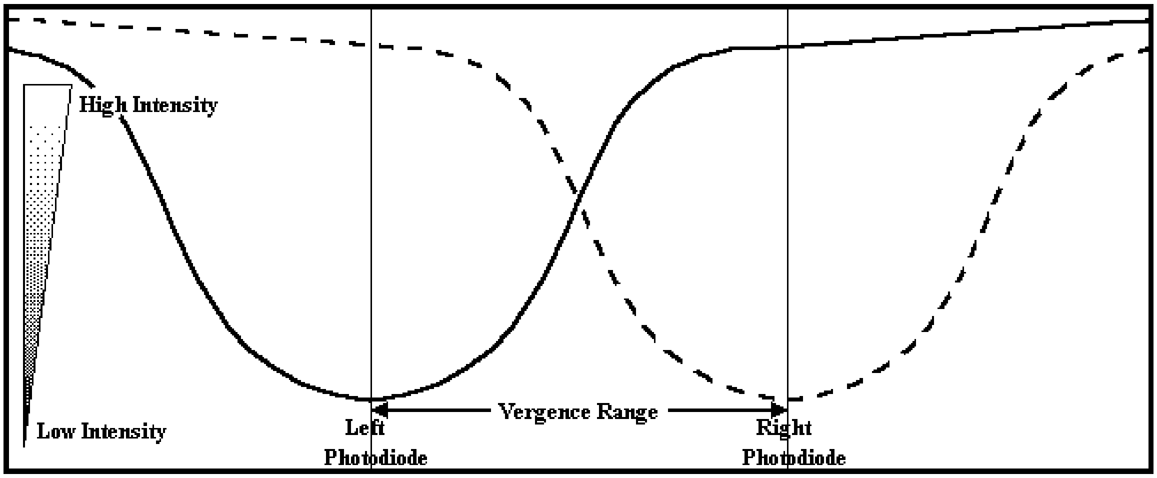

Figure 4: Intensity measurement graph of two photodiodes from one eye: As the pupil points toward the photodiode, the intensity of reflected infrared light is at lowest. When the white part of the eye is near the photodiode, the intensity is higher.

The algorithm, implemented in Interactive C, first stored the minimum and the maximum of the intensity of each photodiode. Then the ranges of each photodiode were adjusted to be proportional to the other. At each instance, the algorithm subtracted the proportioned measurements. The result of this calculation over the full range of eye movement resulted with a smooth curve. The result gave negative values when the eye was near one photodiode, zero when in between the two, and positive when the eye was near the other.

3.4 Actuators

The processor translated the calculated value to a control signal. Then signals drove the servo motor to move to a specific position. Since the servos were driven using pulse-width-modulation(PWM), the processor was programmed in C to generate these signals to move the servos.

4 Conclusion

This section discusses the results and the problems with the project and the ideas for future implementation. Then it suggests other projects using this basic concept.

4.1 Result

The result of the project is a functional vergence tracking device. The implementation cost is very low because of the inexpensive sensors used. A frame with moving eyes with approximate dimensions of a human head were made to test the project. As the eyes changed their vergence, the robotic eyes moved immediately to mimic the change.

The instrumentation amplifier filtered out virtually all the noise factor. The glasses somewhat functioned even with only the external light by turning off the infrared emitters.

Although the change in lens focal length could not be implemented due to time and budget constraints, adding these functions in the future would be simple.

4.2 Problems

The simple algorithm of the program gave little flexibility in the placement of the device on the eyes. Therefore if the glasses were worn crooked, the robotic eyes did not move with a full range of motion. These errors, however, can be corrected using better algorithms.

Sensitivity and accuracy of the movement were trade-off factors in the algorithm. Therefore movement with different settings should be experimented with to find the optimum setup. Better algorithm can make the two factors independent of each other.

4.3 The Future

High intensity near infrared light is harmful to the eyes. In the future, special low intensity near infrared emitter with highly sensitive photodiodes will be used to collect accurate data. Otherwise, Electro-oculo-gram detectors could be used. With Electro-oculo-gram detectors, movement signals would be easily localized with noise signals shielded.

A variable lens made of plastic to mimic the human lens could be more natural to use. These lenses would function to restore the accommodative functions of the natural lens.

If the auto-focusing mechanism becomes small enough, it could be used directly on the moving eye tracker, to bypass the calculation of the distance. In this idea, the control for accommodation would be only dependent on the visual path of the each lens.

4.4 Other Application

This concept of vergence and accommodation of the lens is useful in many other applications. Recently emerging projects with potential application of the concept include robotics eyes and virtual reality glasses.

Currently, virtual reality glasses fails to give realistic views of the virtual objects because of the fixed position of the display. Quite often, this artificial view of the image exhausts the eyes. Implementation of changing vergence with accommodation on the images will make virtual reality glasses more natural.

Further more, the range of the images in each eye would be larger with a small display. This would be because the display could move directly into the visual path of the eyes.

5 References

Flynn, A. and Jones, J. *Mobile Robots: Inspiration to Implementation*. A K Peters, Ltd. Wellesley, MA, 1993.

Krishnan, V. V., Phillips, S., and Stark, L. Frequency Analysis of Accommodation, Accomodative Vergence and Disparity Vergence. *Vision Res. Vol. 13, pp. 1545-1554.*, 1973.

Phillips, S. and Stark, L. Blur: A Sufficient Accomodative Stimulus. *Documenta Ophthalmologica 43,1: 65-89.*, 1977.

6 Appendix

6.1 Interactive C Code

```
/* Assign global variables */
float i[2], ib[2],j,k;
int lave,rave;
int left[2],right[2];
int lmin[2],lmax[2];
int rmin[2],rmax[2];
int lpos[2],rpos[2];
int difl[2],difr[2];
float llave,lsize,lrange;
float rrave,rsize,rrange;
float mid[2];
int tmp;

/* Set starting values */
int photo = 0;
float sense=0.5;
float max=7.0;
float min=2.0;
float dv=200.0;

/* Getting value for Photodiodes */
int p_diode(int ch)
{
  bit_set(0x1039, 0b10000000);
  bit_set(0x1030,0b00010000);

  while ((peek(0x1030) & 0b10000000) == 0) {}
  photo = peek(0x1030+ch);
  return photo;
}

/* Initialize Left and Right servos */
void init_servo(int mech)
{
mid[mech] = 4.5;
i[mech] = mid[mech];
left[mech] = p_diode((mech*2)+1);
right[mech] = p_diode((mech*2)+2);
lmin[mech] = left[mech];
lmax[mech] = left[mech]+1;
rmin[mech] = right[mech];
rmax[mech] = right[mech]+1;
init_motors();
ib[mech]=i[mech];
}

/* Turn servos */
void servo(int mech)
{
/* get left and right photodiode value */
if (mech==0) {
left[mech] = p_diode(2);
right[mech] = p_diode(1);
} else {
```

```
left[mech] = p_diode(3);
right[mech] = p_diode(4);
}

/* find min and max of each */
if (left[mech]<lmin[mech]) lmin[mech]=left[mech];
if (right[mech]<rmin[mech]) rmin[mech]=right[mech];
if (left[mech]>lmax[mech]) lmax[mech]=left[mech];
if (right[mech]>rmax[mech]) rmax[mech]=right[mech];

/* find min and max pos */
tmp=left[mech]-right[mech];
if (tmp<lpos[mech]) lpos[mech]=tmp;
if (tmp>rpos[mech]) rpos[mech]=tmp;

/* determine position */
lsize=(float) (rpos[mech]-lpos[mech]);
if (rpos[mech]==lpos[mech]) lsize=1.0;
lrange=(float) tmp-(float) lpos[mech];
llave=(max-min)*(lrange/lsize);
i[mech]=min+llave;

/* don't move beyond boundary */

if (i[mech]<min) i[mech]=min;
if (i[mech]>max) i[mech]=max;

i[mech]=(float) ((int) (i[mech]* dv))/dv;

/* move with certain sensitivity */
if (((i[mech]-ib[mech])>sense) || ((ib[mech]-i[mech])>sense)) {
        i[mech]=i[mech]*.3+3.3;
        motor(mech,i[mech]);
        ib[mech]=i[mech];}

}

/* Main function that just loops */
void main()
{
/* initialize servos */
init_servo(0);
init_servo(1);

/* infinite loop */
while(1) {
  servo(0);
  servo(1);
}
}
```