Low-Cost Ergonomic Low Vision Aid Development

A Thesis

Submitted by

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CERTIFICATE

This is to certify that the thesis entitled "**Low-Cost Ergonomic Low Vision Aid**", submitted by **Mukul Mohan (EE08B043),** to the Indian Institute of Technology, Madras, for the award of the degrees of **Bachelor of Technology in Electrical Engineering** and **Master of Technology in Microelectronics & VLSI Design**, is a bonafide record of the project work done by him under my supervision. The contents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

KEYWORDS: Low Vision, Low Cost Aid, Portable Aid, Optical Prototype, Digital System

The eyes are probably the most important of our senses and any form of defect in this vital sense can hamper daily life activities to a great extent. Low vision is one such defect of eye which results in poor vision. It results from damage caused to the retina or the optic nerves. No form of conventional glasses can correct this defect and people with such problems need more elaborate visual aids. This is majorly seen among the old but there cases of this condition occurring in the younger demographic. "A major constraint in the delivery of low vision care in developing countries such as India is the non-availability of low cost, good quality, low vision devices" [2]. Most of the aids available in the market are extremely expensive as most of them are imported from other countries. Even though there are aids available which are very effective most of them are riddled with portability issues.

With over 11 million people in India with this defect, this is a problem that needs to be addressed soon. The objective of the project is to design and implement a low cost visual aid for people with the condition of low vision and subsequently develop a ready-to-market prototype. The aid had to be designed in such a way that it was effective, portable as well as a patient using such a device had to be integrated into the society well.

The device went through various different iterations during the design process with the optical design was given by Ms. Sailaja from Sankara Nethralaya, Chennai. Through the process, 3 prototypes were developed with each design having significant improvements from the previous prototype. An optical prototype using a two lens system was thus developed and was tested on 9 low vision patients, and with valuable feedbacks from patients a more robust digital system was then developed.

ACKNOWLEDGEMENT

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Mukul Mohan

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INTRODUCTION

1.1 Low vision

The visual acuity of people with low vision varies widely, but, in general, low vision is defined as a condition in which a person's vision cannot be fully corrected by glasses, thus interfering with daily activities such as reading and driving. Low vision is more common among the elderly, but it can occur in individuals of any age as a result of such conditions as macular degeneration, glaucoma, diabetic retinopathy, or cataracts. Each of these conditions causes different types of effects in a person's vision, however, there are a few generalizations which can be made to make an effective low vision aid**.** It helps to see through the eyes of someone who has low vision as it helps in understanding the problem clearly.

1.2 Types of Low vision

1.2.1 Macular degeneration

This is type of low vision defect which is generally seen in older adults and is seen as an age related disorder. The macula is the central area of the retina, which provides the most detailed central vision and its degeneration causes this defect. The effects of this disorder is central vision loss due to damage in the retina. People with macular degeneration are unable to read or recognize faces. “An ever-increasing number of people are at risk of macular degeneration as populations grow and demographic shifts towards the predominance of the older age group.” [3]

Figure 1.1 Macular Degeneration

1.2.2 Glaucoma

Glaucoma is a condition that continuously damages the eye's optic nerve and gradually leads to blindness with ever decreasing peripheral vision. This happens when the pressure created by the eye fluid called intraocular pressure increases. The increased pressure damages the optic nerve that which is responsible for sending images to the brain. Without proper treatment glaucoma can lead to complete blindness within a year. The permanent effects of glaucoma is one of the major cause of peripheral vision loss or tunnel vision.

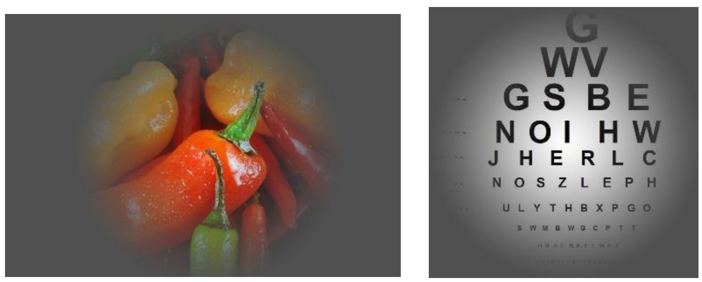

Figure 1.2 Glaucoma

1.2.3 Diabetic retinopathy

As the name suggests, Diabetic retinopathy is caused by damage to the retina caused by complications of diabetics, which can eventually lead to blindness. This condition is essentially caused by hemorrhages in the eye which can lead to blurry vision.

Figure 1.3 Diabetic retinopathy

1.2.3 Cataract

Cataract is caused by clouding of the lens which leads to a decrease in the quality of vision. It is the most common cause of blindness and usually treated with surgery, which essentially cleans the lens of this clouding. This defect is again seen in prominence among the older demographics. Approximately 90% of patients can achieve a corrected vision of 20/40 or better after surgery [10]. People with cataract have poor color separation and cannot appreciate changes in contrast. They have problems driving, reading and recognizing faces [11].

Figure 1.4 Cataract

1.3 Inference

These low vision defects could be generalized into three major problems

- Field of View loss, where the patient loses a part of his/her field of view.
- Quality loss, which would mean such a person would see blurry images and have poor color separation.
- Contrast loss, where either the contrast of the image being seen is large or it is too low for objects and details to be recognized.

II

PRESENT SOLUTIONS

2.1 Low vision aids

The vast majority of patients with low vision can be helped to function at a higher level with the use of low vision devices. At present in the market there are aids which solve near vision problems and there are products that solve far vision problems.

2.1.1 Near Vision

The low vision solutions of today for near vision are majorly magnifiers which come in various different sizes some are portable and some are not. Each of these magnification tools are intended for different uses. Some of these magnification tools also employ image enhancement and contrast enhancement algorithms to display text distinctly.

Figure 2.1 LED Magnifier

Figure 2.2 Digital handheld Magnifier

Figure 2.3 A Bulky text Magnifier

2.1.2 Far Vision

The solutions that exist for Far Vision is focusing telescopes, which implement optics to bring the object being viewed into focus. There are manual as well as auto focus systems present in the market. People using such a solution as can be seen in the figure below, cannot be integrated well into society, and a person using such a device would easily stand out among a group of people.

Figure 2.4 Spectacle mounted low vision aid

2.2 Inference

Some generalizations that could be made from the above described defects is that the low vision aid developed must be capable of detection of objects and should be able to display the prominently, increase or decrease contrast depending upon the condition. Also magnify the image such that the patient has a better image projected on the retina. The device also had to be designed in such a way that the user is integrated into the society with ease. With these ideas in mind the development of the prototype was done. At present there are specific aids aimed at near and far vision, so a unified solution for far and near vision was also put forward. The devices available in the market are costly and most patients cannot afford them. So an affordable Low Vision aid was to be developed especially in a country like India which has 10% of the world’s low vision patients [3]. The first objective was to provide magnification.

III

PROTOTYPE I

3.1 Optical Design

A telescopic system was decided to be developed to address magnification. Such a system would have restrictions on its weight and dimensions as it would have to be mounted on a patient's spectacles. The overall design of the prototype would have to be have to be a compromise between the image quality and the weight and dimensions of the system. The optical design provided by Sankara Nethralaya had the objective and the eyepiece lens placed at a distance of 90 - 105 mm from each other. The eye piece was a concave lens of focal length 10 cm while objective was a convex lens of 40 cm which provides an effective magnification of 4x in theory. Since designing the device with dimensions more than 105 mm will be ergonomically unsuitable, a folded system was considered. To keep the dimensions of the device at a minimum, penta prisms were used to increase the optical path length.

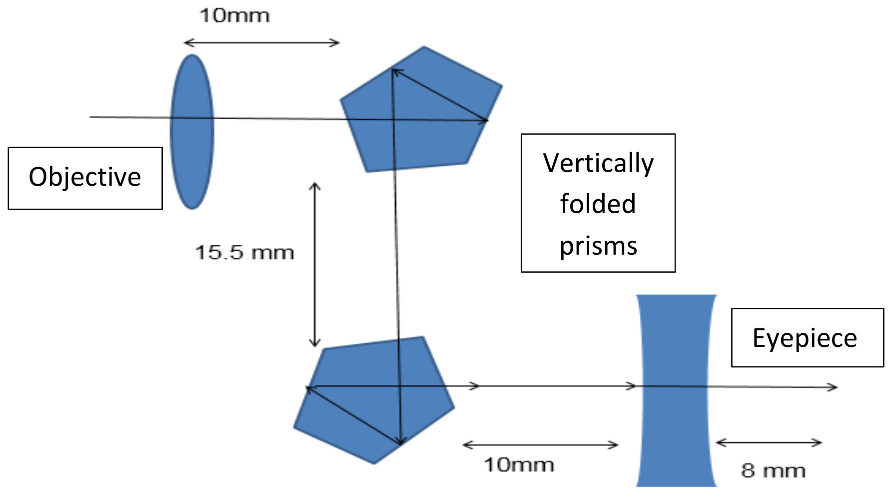

Figure 3.1 Folded Mechanism of Optics (side-view of the optical design) [4]

Since the prism increases the path length substantially a more compact system could be achieved. Also due to even number of reflections taking place the final image would still be erect. For focusing the system the objective had to be moved along a 10mm track depending on the distance at which the device needed to focus.

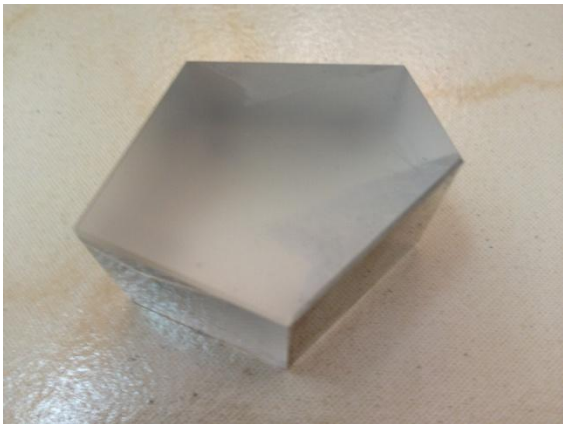

Figure 3.2(a) Prism

Figure 3.2(b) Lens

3.2 Floppy Disk Mechanism

Conventional floppy drives contains a leadscrew coupled with a stepper motor to achieve linear actuation. The floppy drive also has an IR break beam switch which is essentially used to calibrate the floppy drive. This feature was a plus as this could be used to calibrate the device. To prototype the design as well as to test the electronics and the designed optics, old floppy drives and CD drives were used to salvage miniature stepper-motors. The design was periscopic in nature with one lens placed on top of the other. Two penta prisms were to be used to increase the path length.

3.2.1 MSP430

The MSP430 is a mixed-signal microcontroller family developed by Texas Instruments. It is built around a 16-bit CPU, the MSP430 is designed for low cost and, specifically, low power consumption embedded applications. The Value Series has flash-based Ultra-Low Power MCUs with up to 16 MIPS and a 1.8–3.6 V operation. The MSP430G2231 Launchpad device of the Value Series which was used for the prototype comes with up to 16kB Flash, 512B RAM, 16MHz CPU speed and integrated peripherals such as 8ch 10-bit ADC, timers, serial communication (UART, I2C & SPI). These features along with the low power operational capabilities and the availability of the MSP430 made it the right choice for the prototype.

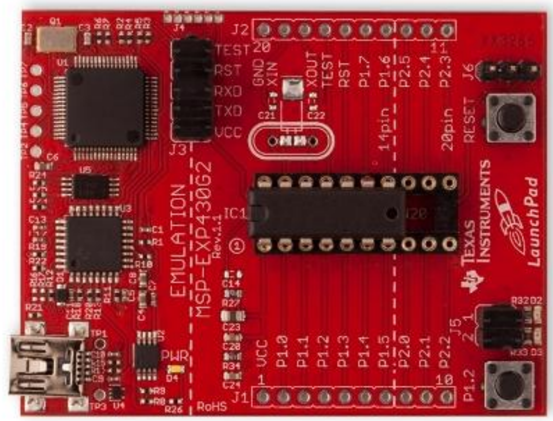

Figure 3.3 Texas Instruments MSP430 Microcontroller

3.2.2 L293D

Since the microcontroller output can only be a very small value of current (6mA), an H-bridge circuit was needed to supply the required current to the stepper motor (~200mA). An H bridge is an electronic circuit that enables a voltage to be applied across a load in either direction. An L293D circuit was used as it is widely used for hobby projects and so its use and details was well documented. The L293D is a monolithic integrated, high voltage, high current, 4-channel driver. Basically this means using this chip you can use DC motors and power supplies of up to 36V, with a maximum current of 600mA per channel.

3.2.3 Stepper Motor

A stepper motor is a kind of brushless DC electric motor that breaks a full rotation into equal steps. The motor's shaft position can be programmed to move and hold its position at one of these steps without the use of any feedback sensor (an open-loop controller), as long as the motor is carefully used to suit the application. Stepper motors provide a simple way for positional control and speed control without the use of any feedback sensors. The basic operation of a stepper motor is described as follows, the shaft moves a precise number of degrees each time a pulse of electricity is sent to the motor. As the shaft of the motor moves only by that many number of degrees depending upon the signal from the microcontroller, you can control the pulses that are sent and thereby control the positioning and speed.

The rotor of the stepper motor produces torque by the interaction between the magnetic field of the stator and rotor coils. The strength of the magnetic fields is directly proportional to the amount of current that is sent to the stator coil and the number of turns in the windings.

Figure 3.4 Floppy Drive

The floppy drive contained a 24 step stepper motor which means, the rotor will require 24 pulses of electricity to move the 24 steps for one complete revolution. Another way to say this is that the rotor will move precisely 15° for each pulse of electricity that the motor receives. The number of degrees the rotor will turn when a pulse of electricity is delivered to the motor can be calculated by dividing the number of degrees in one revolution of the shaft (360°) by the number of poles (north and south) in the rotor. In this stepper motor 360° is divided by 24 to get 15°.

3.2.4 Implementation

The design used a leadscrew, rotated with a stepper-motor whose exact number of steps could be controlled using the MSP430. A metal piece sitting in the screw lines would move the lens forward as the motor rotated. Every time the screw turned, the pin would move on the grooves and there would be linear motion of the actuator. A software debounce of the push buttons was implemented to remove any erroneous actuation. The system was powered using a 12V rechargeable lead acid battery, for testing the mechanism and the resolution of actuation achieved. A Half Step Sequence was used to actuate the stepper motor. In Half mode step sequence, motor step angle reduces to half the angle in full mode. So the angular resolution is also increased i.e. it becomes double the angular resolution in full mode. Also in half mode sequence the number of steps gets doubled as that of full mode. Half mode is usually preferred over full mode. Thus an angular resolution of 7.5° was achieved. Table below shows the pattern of energizing the coils.

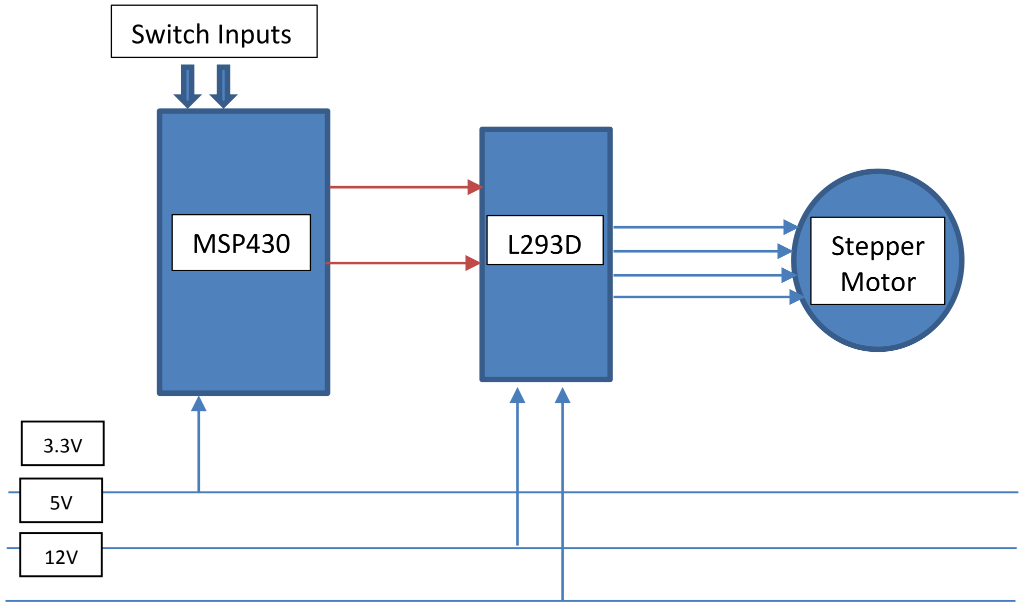

Figure 3.5 System Block Diagram

Step	Phase a	Phase b	Phase $\bar{a}$	Phase $\bar{b}$
0	1	1	0	0
1	0	1	0	0
2	0	1	1	0
3	0	0	1	0
4	0	0	1	1
5	0	0	0	1
6	1	0	0	1
7	1	0	0	0

Figure 3.6 Half Stepping Sequence

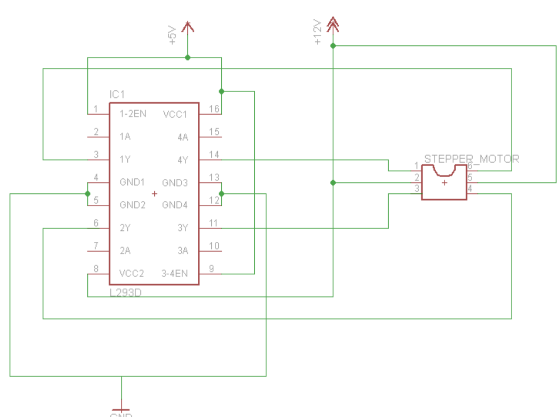

Figure 3.7 Stepper Motor/L293D connections

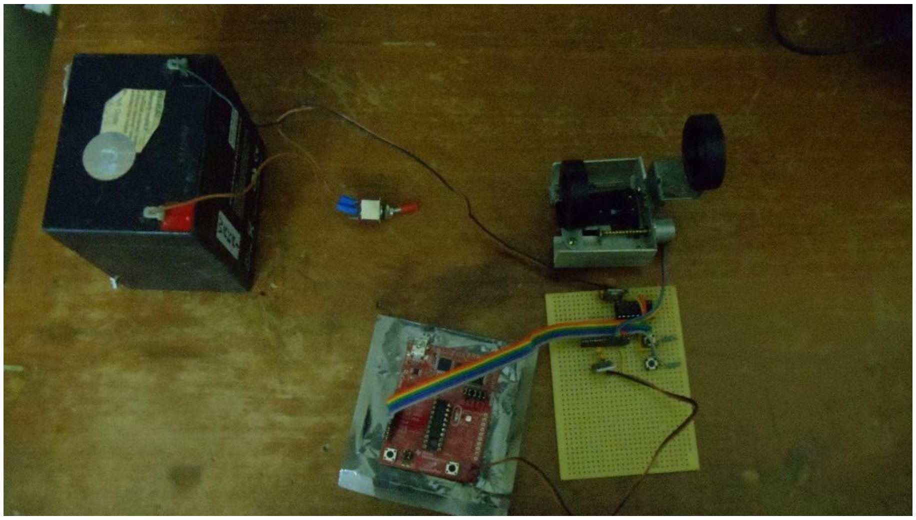

Figure 3.8 Floppy Drive Prototype

3.2.5 Results

The pitch of the leadscrew was 2mm and with a stepper motor of 24 steps minimum step of less than 0.1mm was achieved. There was a lack of robustness and the physical dimensions of the system made it hard for a patient to easily use the device. The prototype was heavier than what was thought and as the motors were drawing high current it meant that the power drawn was high. It made a lot of noise because of the mechanical parts involved, also the stepper motor would get heated after continuous use. This made the prototype very difficult to use if it were to be mounted on the head. Also such a prototype would be very difficult to manufacture as floppy drives would have to be salvaged for manufacturing which was not very feasible.

3.3 Stepper Motor & Rack and Pinion

Figure 3.9 Testing the Mechanism

The vertical alignment of the optical system in the floppy drive prototype increased the height of the system and so to make it ergonomic a new horizontal folded system was proposed. The floppy drive mechanism was thus changed, but we decided to still use the stepper motor and see if a rack and pinion mechanism would give better results. As the pinion had a total circumference of about 8mm to achieve an accuracy of less than 0.3mm we had to use a 48-step stepper motor. The electronics of the system still remained the same.

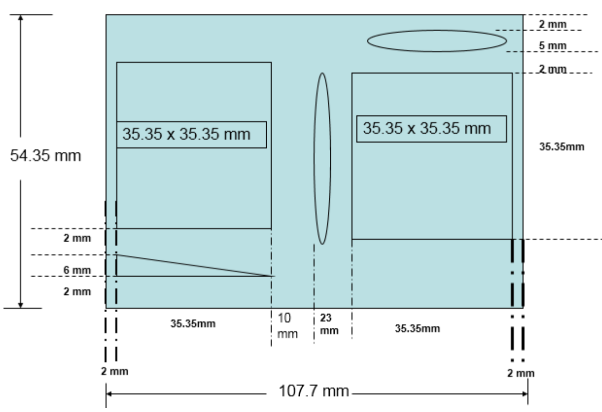

Figure 3.10 Optical Layout [4]

Figure 3.11 Slider

‘

3.3.1 Implementation

A smooth miniature slider was used on which the rack mechanism was placed, the objective lens was also placed on the same slider and as the slider was moved the lens moved. The optical design needed the objective to move a distance of 10mm.

Figure 3.12 Stepper Motor Prototype

3.3.2 Results

The device fit in a box of 120mm * 80mm * 40mm. Most of the components that were needed were commercially available and thus the mechanism was easy to replicate and make. Though this prototype gave us the flexibility of easy large scale manufacturing, the prototype was still was riddled with the problems some of the problems of the previous prototype like heating, excessive noise and rattling. Due to the motor backlash sometimes the 0.2mm calculated resolution would be crossed. The power consumed by the prototype was also very large for the function it performed. The use of a micro stepping stepper motor driver was initially finalised for a smoother motor motion but as the power consumption and heating issue of the stepper would still prevail this idea was abandoned.

IV

PROTOTYPE II

4.1 Linear Actuator

4.1.1 Implementation

A linear actuator was chosen for providing the linear motion. The product was redesigned to incorporate the linear actuator and the optical system was also changed to reduce the size of the system. The main aim of the design was to address the noise and heating issues of the precious prototype. Also the power consumption was to be reduced. The PQ12 actuators from Firgelli was chosen. These motors are a complete, self-contained linear motion devices with position feedback for position control capabilities. This linear actuator has a stroke of 20mm and a positional accuracy of ±0.1mm. The motor also has a max stall current of 220mA at 12V supply. The motor has a potentiometer feedback for determining the position of the actuator shaft. It could provide a push of 15N which easily was enough for our needs. The product was redesigned to incorporate the linear actuator and the optical system was changed to reduce the size of the system. The prototype used the same motor driver (L293D), the board schematic is shown below. The board was designed using Eagle PCB designing software and this gave a neat and more robust electronics.

Figure 4.1 Linear Actuator

4.1.2 Results

The linear actuator removes the need for a rack and pinion and also significantly reduces the power demands. The controls for the linear actuator are very easy and this means reduced power consumption on board the controller. Also the size significantly reduces because of the small size of the actuator. The design also improves the quality of the image as more light passes through the lens than before. As the linear actuator replaced the stepper motor, rack and pinion mechanism and the slider, the weight of the system significantly reduced. The final device was more portable as the microcontroller was integrated into the motor driver board itself.

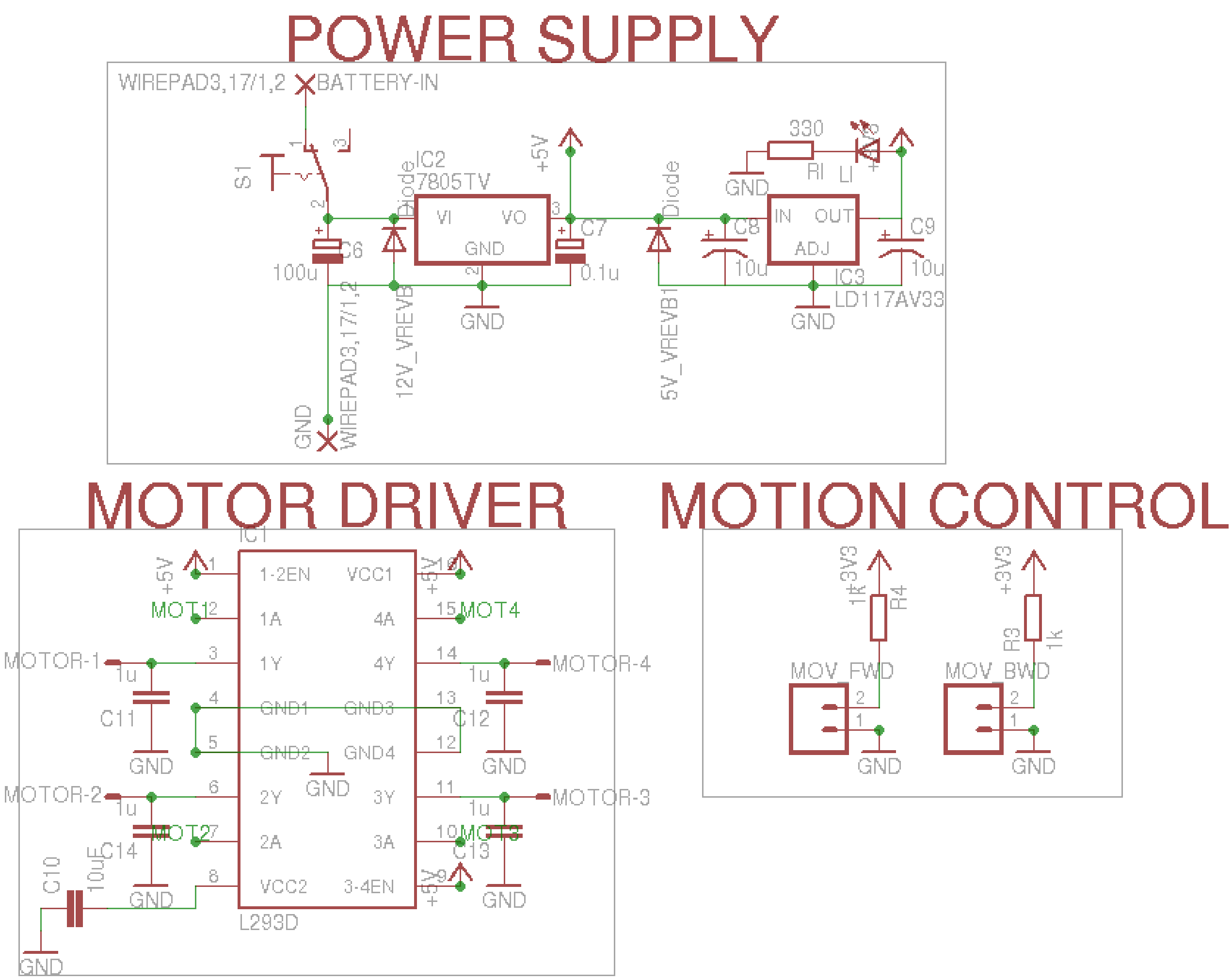

Figure 4.2 Board Schematic

4.2 Head Mounted System

4.2.1 Implementation

Few changes were made to the previous prototype so that the size of the system is reduced and provision was provided to attach the system on a head mount for testing. In the new design, the actuator was placed above the prism for reduction in the size of the system. The frame was made through laser cutting of sheet metal and afterwards bending it to suitable shape. The frame was powder coated to prevent any form of rusting and thus better off during testing of the device. As the device was now packaged the linear actuator stroke had to be limited from its full 20mm stroke. As the objective was placed close to the prism, this meant that the motion of the actuator had to be limited to 10mm. This was done by reading the potentiometer feedback using an ADC and restricting movement depending upon the feedback value.

4.2.2 TB6612FNG Controller

The TB6612FNG is a miniature dual motor driver that is perfect for interfacing DC motors to a microcontroller, in our case we needed it to interface with the linear actuator. The MOSFET-based H-bridges are much more efficient than the BJT-based H-bridges used in older drivers like the L293D. The TB6612 motor driver used on the carrier board has a peak current rating of 3 A per channel which is for quick transients like when the motor is being switched on. The continuous maximum rating of 1 A is dependent on various conditions, such as the ambient temperature. This controller was used to further reduce the power consumption, being more efficient than the L293D this was possible. Another positive was that 3.3V line could be used as the logic voltage for the driver, this meant that the IC (7805) for generating 5V (required for L293D logic supply) could be altogether omitted. This meant that the electronics could be fit into an even smaller area.

Figure 4.3 TB6612FNG Controller

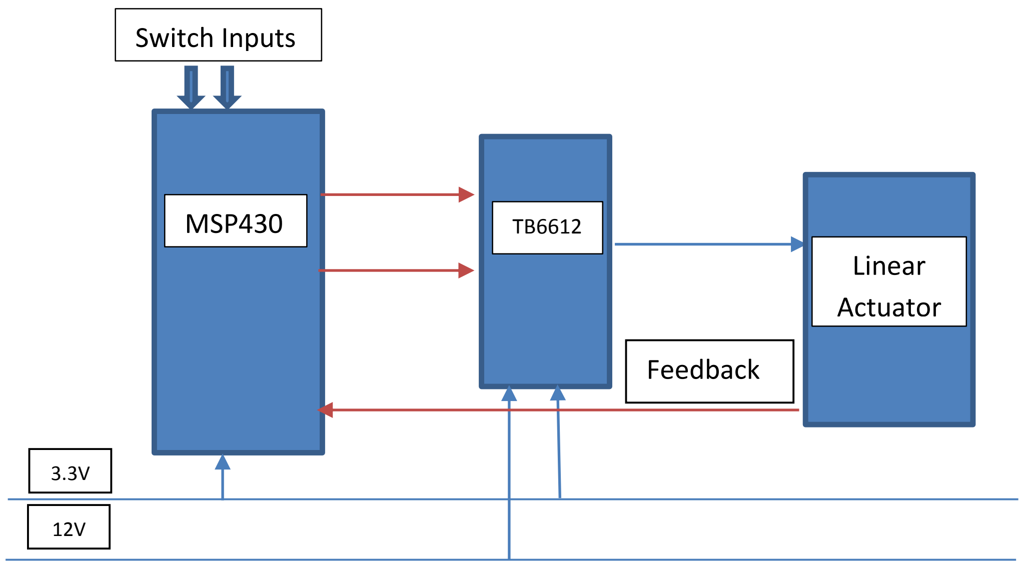

Figure 4.4 System Block Diagram

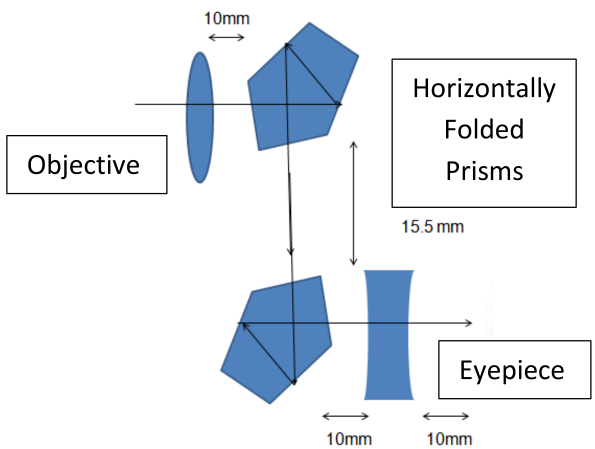

Figure 4.5 Top View of Optical Design [4]

4.2.3 Results

The device size was about 100mm X 60mm X 55mm. The device consumed about 150mA * 11.1V = 1.655 W of power during operation. This meant that the device could go for more than 6 hours in continuous actuation using a Lithium Polymer battery pack of 11.1V (1000mAh). A 1 page manual was written about using the device so that the patient would find it easy to use the device with minimum hiccups. This means that the design can be used to help with the problem of Low Vision.

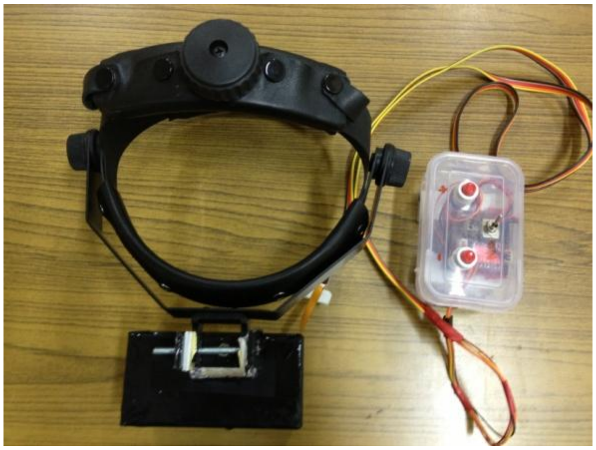

Figure 4.6(a) Head mountable prototype with control board

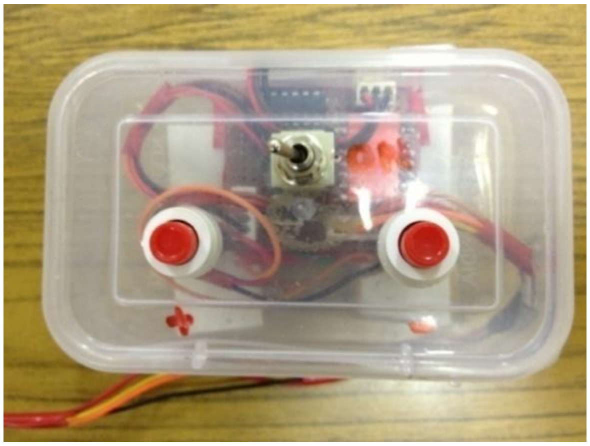

Figure 4.6(b) Control board

Though the device is heavier and bulkier, the design was to be done such that this device could be worn on any glasses eventually. The frame of the final device was made using rapid prototyping so as to make it lighter, an extra provision of wearing the device was incorporated, to further reduce the weight.

Figure 4.7 Rapid Prototyped Model

The prototype was tested on 9 low vision patients at the Low Vision Clinic at Sankara Nethralaya [4]. The table below shows the results of the testing with rating between 1-5, where a rating of 1 meant Excellent and a rating of 5 meant Extremely Poor.

Serial No	Diagnosis	Previous History of use of low vision device	Requirement for distance	Distance required (m)	Amsler	Contrast sensitivity	Distance measured (m)	Ease of handling	Ease of focussing	Quality of image with telescope	Ability to see Marsden ball	Ability to watch television
1	RETINITIS PIGMENTOSA	NO	RECOGNIZING FACES AT DISTANCE	4	TUNNEL VISION	DEFERRED	3	4	3	3	4	5
2	PARAFOVEAL TELANGLECTASIA	NO	WATCHING TV	6	METAMORP HISM	DEFERRED	3	3	3	2	3	4
3	COLOBOMA	NO	SEEING BUS NUMBERS	6	DEFERRED	DEFERRED	1	2	1	3	4	5
4	RETINITIS PIGMENTOSA	NO	RECOGNIZING FACES AT DISTANCE	6	TUNNEL VISION	DEFERRED	2	3	4	3	4	5
5	FOVEAL HYPOPLASIA	NO	READING BLACK BOARD	6	NORMAL	3/30.	3	4	1	3	4	4
6	RETINITIS PIGMENTOSA	NO	READING BLACK BOARD	3	NORMAL	3/4.8.	3	4	3	4	4	5
7	RETINITIS PIGMENTOSA	NO	WATCHING TV	4	TUNNEL VISION	0.5/38.	2	4	1	4	3	5
8	RETINITIS PIGMENTOSA	NO	READING BLACK BOARD	6	NORMAL	1/30.	2	3	2	4	5	5
9	CONE DYSTROPHY	YES	READING BLACK BOARD	6	NORMAL	DEFERRED	2	1	1	3	3	1
							2.33	3.11	2.11	3.22	3.78	4.33

Figure 4.8 Patient feedback [4]

(a) Eye test board (b) Marsden Ball

Figure 4.9 Testing Schemes

Though in theory the magnification to be achieved was 4x, but approximately around 3x magnification was achieved by the prototype. The field of view of the prototype was approximately calculated to be 18º which was very small. All the patients reported that there was improved magnification. For few patients, the vision was clearer with the device and for few the quality of the vision did not improve because of their ocular condition. Almost all the patients had a problem with the device dimensions which was bulky and essentially not ergonomic. Few of the patients had difficulty in focusing on objects due to the decreased field of view. With this feedback a system with increased field of view, better ergonomics and better quality of the image was aimed to be developed.

V

PROTOTYPE III

Figure 5.1 Vuzix Wrap 920

5.1 Vuzix Wrap 920

The Vuzix Wrap 920 provides a portable 67-inch screen viewed from three meters. Two AA batteries afford up to six hours of continuous use. This device takes Composite AV cable (RCA) as input. It also comes with a VGA adapter which can be purchased separately.

5.2 Blackfin BF533

Initially an FPGA was considered as the processing core of the device and a few designs were implemented on it, but due the large prototyping time required to get the prototype working, this idea was not pursued. The ADSP-BF533 provides a high performance, power-efficient processor choice for real time video processing applications. The high performance 16-bit/32-bit Blackfin embedded processor core, with flexible cache architecture, an enhanced DMA subsystem, and t dynamic power management (DPM) functionality gives a flexible platform. Also a large on-chip SRAM makes implementation of image processing algorithms more efficient.

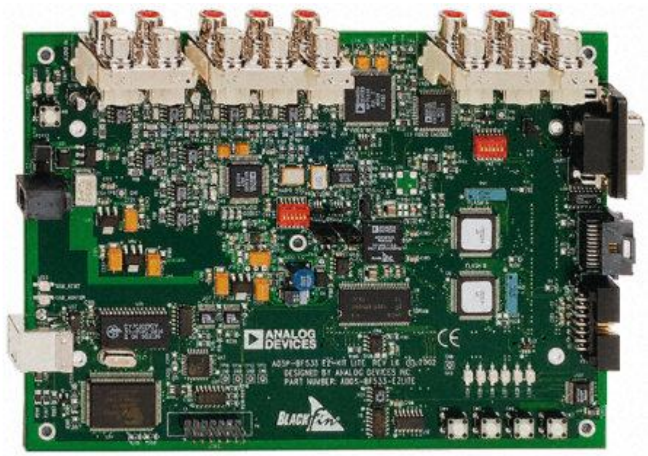

Figure 5.2 Analog Devices Blackfin 533

A camera was interfaced with the analog video port of the processor. The Blackfin processor was used to implement a Sobel edge detection routine on the camera feed and the edge detected output was then displayed on the Vuzix Wrap 920. This edge detection routine could detect people in a room and depending upon thresholds set could identify faces. All this was subject to the lighting conditions in the room.

5.2.1 Sobel Edge Detection

As described earlier, some LV patients perceive foggy or blurred images, hence they are not able to identify objects and faces. An increased gain in the high frequencies can help patients to identify them. The contrast enhancements that we propose consist of extracting the edges and superimposing them with the original image at the same position with a polarity that depends on the context. This means that we redraw a white trace on a dark background, as can be seen in the figure below. Sobel Edge Detection Algorithm is an effective way for detecting the edges of objects in a frame.

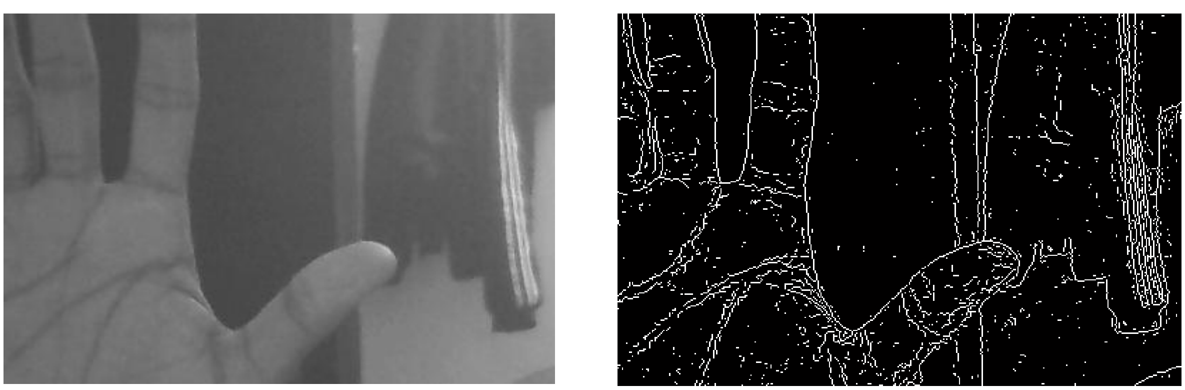

Figure 5.3 Sobel Edge Detection Implemented in Matlab

One of the fundamental steps in Image Processing is edge detection which is generally a precursor to more advanced techniques like feature extraction and object segmentation [6]. This algorithm finds outlines of an object and boundaries between objects and the background present in an image. An edge-detection filter used in conjunction would improve the appearance of blurred or anti-aliased video streams. The most common method for detecting edges is by applying the derivative operator. There are two types of derivative approaches for edge detection namely first order and second order. The first order derivative approach uses the derivative calculated in several directions and combining the result of each gradient. The values of gradient magnitude and orientation is computed using two differentiation masks. The Sobel edge detection algorithm uses a 3 x 3 table of pixels to store a pixel and its neighbors in the process of calculating the derivatives. This 3 x 3 table of pixels is called the convolution table, as it moves across the image in a convolution style algorithm. For a given image H, horizontal and vertical gradient of each pixel (*x*, *y*), are calculated as shown in “(A)” and “(B)”.

$$G_X(x,y) = \begin{matrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{matrix} * H(x,y) \qquad \text{(A)}$$

$$G_Y(x,y) = \begin{matrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{matrix} * H(x,y) \qquad \text{(B)}$$

In each pixel (x, y), the approximations of the horizontal and vertical gradients can be combined as shown, to obtain an approximation of the gradient value:

$$G(x,y) = \sqrt{G_X(x,y)^2 + G_Y(x,y)^2}$$

Typically, an approximate magnitude is computed using:

$$G(x,y) = |G_X(x,y)| + |G_Y(x,y)|$$

The orientation of gradient can be calculated as follows:

$$\Theta(x, y) = \text{Arctan}\left(\frac{G_Y(x,y)}{G_X(x,y)}\right)$$

The reason for using Sobel operator is that it is relatively insensitive to noise and also has small convolution masks when compared to other operators such as Robert operator, two-order Laplacian operator and others. It is the one of the simplest operators which however gives corrects results.

5.2.2 Results

The connected camera would capture frames and send them to the Blackfin BF533 which would then detect the edges and display the edge detected frame. The frame rate achieved was 0.5 frames per second for real time processing. Though it was a good way to test the concept the results were nowhere near the required for real time use.

5.3 Raspberry Pi

The Raspberry Pi has a Broadcom BCM2835 system on a chip, which includes an ARM11 based 700 MHz processor. It has a VideoCore IV GPU for image processing computations, and has 512MB of RAM. It does not include a built-in hard disk, but uses an SD card for booting and long-term storage of programs. The device is priced at a very low 35$. The Raspberry Pi Foundation, which is the brain behind the device released Raspberry Pi Fedora Remix, at the time its recommended Linux distribution. This made the Raspberry Pi even more attractive for the application of video processing schemes as with a Linux Distribution ported the prototyping time would drastically reduce.

Figure 5.4 Raspberry Pi

5.3.1 OpenCV

OpenCV (Open Source Computer Vision Library) is a library of programming functions mainly aimed at real-time processing of video (computer vision). It was initially developed by Intel, and now is supported by Willow Garage and Itseez. It is free for use under the open source BSD license for testing, prototyping and implementing design. The library is cross-platform. It focuses mainly on real-time image processing. With Raspberry Pi Fedora Remix ported onto the device the OpenCV2 package could be installed. The compiler gcc was also present in the ported linux distribution which made compiling simple. The code could be written in C/C++ and with vast libraries for image processing being present the development time would be reduced.

5.3.2 Video Processing Schemes [9]

The final product using the Raspberry Pi and the Vuzix Wrap 920 employed the canny edge detection algorithm and the Histogram Equalization Algorithm for contrast enhancement. The move from Sobel to Canny was made as Canny gave better results with edge detection. When compared to the Sobel algorithm implemented earlier the canny edge detection routine was computationally more demanding but due to the processor upgrade this seemed feasibly.

5.3.3 Canny Edge Detection

The Canny edge detection algorithm is considered to be an optimal edge detector. As the Canny edge detection algorithm is susceptible to noise present in raw unprocessed image data, it uses a filter based on a Gaussian, and so the raw image is to be convolved with a Gaussian mask [7]. After this smoothing process edge strength is found by taking the gradient of the image. The resulting image is a slightly blurred version of the original. The magnitude of the edge strength is given by equation (1). The sobel 2D edge detection operator which is used, basically returns a value for the first derivative in the horizontal direction (G_x) and the vertical direction (G_y). From this the edge gradient and direction could be determined as shown below.

$$G(x,y) = \sqrt{G_X(x,y)^2 + G_Y(x,y)^2} \quad (1)$$

$$\Theta(x, y) = \text{Arctan} \left(\frac{G_Y(x,y)}{G_X(x,y)}\right. \quad (2)$$

The edge direction angle is rounded to one of four angles being 0º, 45º, 90º and 135º and a routine called Non-maximum suppression is implemented which gives a better edge output. As the algorithm parameters allow it to be custom-fit for recognition of edges of differing characteristics it is adaptable to various environments. This algorithm is apt for real time implementations on DSPs, or very fast embedded PCs like the Raspberry Pi.

5.3.4 Histogram Equalization

Histogram equalization is a standard method in image processing for contrast adjustment, this algorithm reorders the image histogram to get a contrast enhanced image. [5] This method works best when the pixels in the image have close contrast values. Histogram equalization adjusts the intensities in such a way that it is better distributed on the histogram. Histogram equalization allows areas of lower contrast to gain higher contrast by effectively spreading out the most frequent intensity values [8].

Histogram equalization generally produces unrealistic effects in frames, as it also amplifies the noise present in the frame, which means that the quality of the frame has to be good, which effectively means a good camera is required. However as it greatly improves the contrast of the frame and makes it easier for patients with contrast sensitivity to view objects, these effects are not much of a problem.

The process of Histogram Equalization is described below. Let h be a frame represented by a matrix of size m_r by m_c which contains integer pixel intensities ranging from 0 to I - 1. I is the number of possible intensity values, which is 256 for the 8-bit case. As Let p denote the normalized histogram of h with a bin for each possible intensity. So,

$$P(n) = \frac{\text{Number of pixels with Intensity n}}{\text{total number of pixels}} \qquad n = 0, 1, ..., I - 1.$$

Then the histogram equalized frame g will be defined by

$$g_{i,j} = \text{floor}\left((I-1)\sum_{n=0}^{f_{i,j}} P(n)\right) \qquad (1)$$

Where the floor () function rounds down to the nearest integer. This is equivalent to transforming the pixel intensities, k, of h by the function

$$T(k) = \text{floor}\left((I-1)\sum_{n=0}^{k} P(n)\right)$$

The motivation for this transformation comes from thinking of the intensities of h and g as continuous random variables X, Y on [0, I − 1] with Y defined by

$$Y = T(X) = (I-1)\int_0^X p_X(x)dx \qquad (2)$$

Where p_X defines the probability density function of h. T is the cumulative distributive function of X times (I - 1). Assuming T to be differentiable and invertible, it can then be shown that Y defined by T(X) is uniformly distributed on [0, I - 1], namely that $p_Y(y) = \frac{1}{I-1}$

$$\int_0^y p_Y(z)dz = \text{probability that } 0 \le Y \le y$$

$$= \text{probability that } 0 \le X \le T^{-1}(y)$$

$$= \int_0^{T^{-1}(y)} p_X(w)dw$$

$$\frac{d}{dy}\left(\int_0^y p_Y(z)dz\right) = p_Y(y) = p_X(T^{-1}(y))\frac{d}{dy}(T^{-1}(y))$$

Also as,

$$\frac{d}{dy}T\left(T^{-1}(y)\right) = \frac{d}{dy}y = 1$$

$$\frac{dT}{dx}|x = T^{-1}(y)\frac{d}{dy}\left(T^{-1}(y)\right) = (L-1)p_X T^{-1}(y)\frac{d}{dy}T^{-1}(y) = 1$$

Which means $p_Y(y) = \frac{1}{I-1}$

The equations above illustrates the basic idea of discrete histogram equalization.

Figure 5.5(a) Original Frame

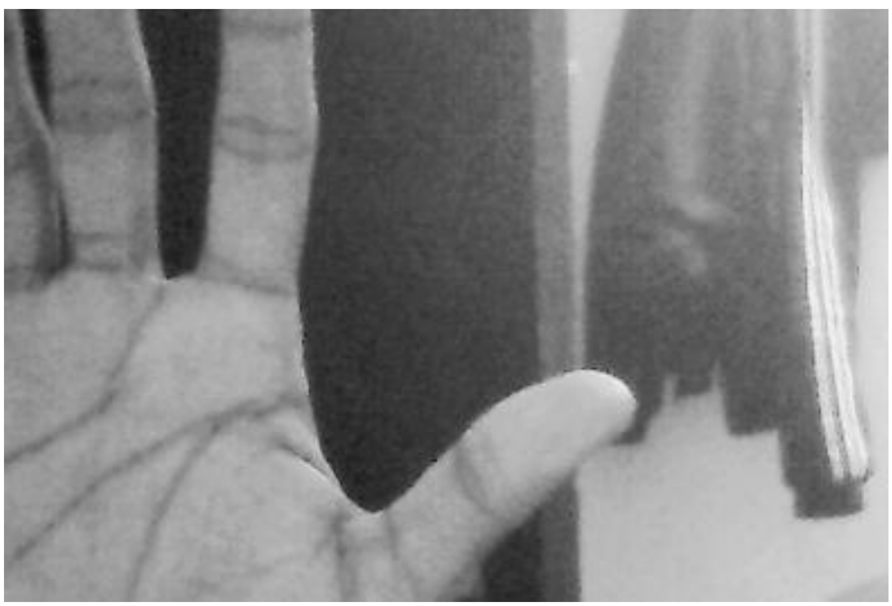

Figure 5.5(b) Histogram Equalization Implemented in Matlab

VI

CONCLUSION

The final prototype now solved low vision problems such as contrast insensitivity, loss of depth perception, night blindness, aversion to glare and slow adjustment from dark to light environments and vice versa. A person using this device could read off a black board more clearly, could recognize faces with ease and could tell bus numbers better. Thus the efficiency of most day to day activities of a low vision patient would be improved by using this product.

FUTURE SCOPE OF WORK

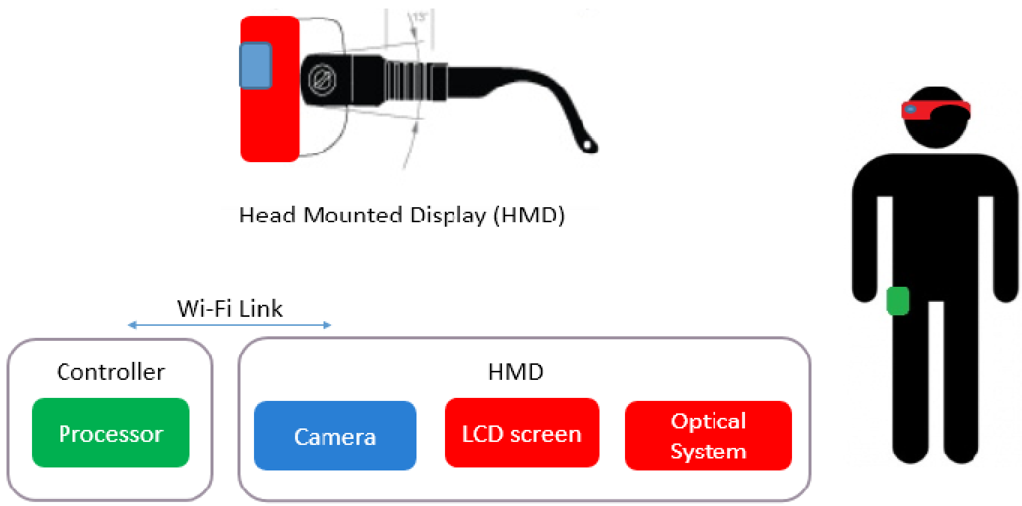

Figure 7.1 Prototype IV

- A portable system to be developed.
- A system that is comfortable and does not make the user standout in a group of people.
- More robust image processing algorithms could be developed. (Such as Face Recognition)
- To make the product customizable a software frontend could be developed. This frontend could be used by the patient to tweak the device to his needs.
- The optical system can be studied and developed so that a low cost low vision device can be developed.
- The system can be connected to the web via 3G which could make it even more powerful as a visual aid tool.
- A better camera to be interface with optical zoom, so that the magnification is crisp.

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