ASSISTIVE WEARABLE LOW VISION AID DEVELOPMENT

A Project Report

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THESIS CERTIFICATE

This is to certify that the thesis titled ASSISTIVE WEARABLE LOW VISION AID DEVELOPMENT, submitted by CHAVATI KRISHNA CHAITANYA, to the Indian Institute of Technology, Madras, for the award of the degree of **Bachelor of Technology**, is a bona fide record of the research work done by him under my supervision. The contents of this thesis, 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

Among our senses, vision is one of the most important sense without which our lives would be very difficult. People with low vision can't be treated by surgery or corrective glasses. So there is a need for them to employ different types of low vision aids . Most individuals today classified as blind actually have remaining sight and, thanks to development in the field of low vision rehabilitation, can be helped to make good use of it, improving their quality of life. But the devices available in the market are very expensive for common people to afford. In this project we try to develop a digital wearable low vision aid which with the help of real time Image processing can help subjects to have a better visual acuity. Our goal is to provide an easy to use, efficient and cost effective low vision aid. The device proved to be very useful when tested on low vision subjects.

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CHAPTER 1

INTRODUCTION

1.1 The low vision problem

This thesis deals with the development of a visual aid for people with low vision. According to WHO, a person with low vision is one who has impairment and/or standard refractive correction and has a visual acuity of less than 6/18 to light perception in the better eye or a visual filed of less than 10 degrees from the point of fixation, but who uses or is potentially able to use vision for the planning and/or execution of a task [7]. Anyone with noncorrectable reduced vision is visually impaired, and can have a wide range of problems. Few people are totally without sight. Most individuals today classified as "blind" actually have remaining sight and, thanks to development in the field of low vision rehabilitation, can be helped to make good use of it, improving their quality of life. The common causes for low vision are macular degeneration, diabetic retinopathy, glaucoma and cataracts. This is majorly seen among the old but there are cases of this condition occurring in the younger demographic. The below are a few statistics about the situation all over the world

- 285 million people are visually impaired worldwide. 39 million are blind and 246 million have low vision.
- About 90% of world's visually impaired live in developing countries.
- Less than 15% of these visually impaired who live in developing countries like India have access to vision enhancement or vision rehabilitation services.
- There are over 1.4 million visually impaired children up to 14 years. The vast majority of visually impaired with low vision conditions in developing countries like India are sent to blind schools despite having usable vision because they don't have access to or cannot afford vision enhancement.

1.2 Available low vision aids

Patients with a visual impairment can maximize their remaining vision through the use of low vision aids and devices. The main principles behind low vision is to enhance contrast, control glare and increase magnification. Most people use multiple low vision aids because each is designed to serve a very specific purpose. Some of the devices are listed below

- Video magnifiers
- Handheld magnifiers
- Telescopic and microscopic spectacles
- Optical filters

1.3 Previous work

An optical system was designed as a low vision aid using pentaprisms. The magnification was achieved by linear actuation of the prism from the eyepiece. It was a head mounted system with a controller for adjusting the amount of magnification. Though the device worked very well for the purpose, it had some limitations. The device was heavy to be head mounted. Due to the mechanical movement, noise and heat were produced. These limitations made the device less easy to use.

1.4 Our Idea

Our approach is to design a Digital wearable device. This device will be using a camera, a processor and a wearable display. We capture the video using the camera and perform real time image processing on it. Such a device would offer the following advantages.

- The device is wearable and mobile which provides significant ease of use. It will be light because it is an electronic wearable display. There will not be any sound or heat produced because of no mechanical movement of the parts.
- Going by a digital approach opens up endless possibilities. We can not only perform magnification but we can also design computer vision algorithms to provide more visual information which can help subjects perceive better. For example,

1. People with bad visual acuity can be helped using magnification.
2. People suffering with poor colour separation will find contrast enhancement helpful.
3. Face detection and obstacle detection techniques can be used to help people who are visually impaired.
4. Machine learning methods can be applied to detect doors, emergency exits and staircases etc.
5. Marker based vision algorithms can be used to help subjects navigate inside a work place and when using elevators.

- There will always be a scope of improvement with the discovery of newer algorithms and methods.

CHAPTER 2

HARDWARE

2.1 Hardware modules

2.1.1 Vuzix display goggles

Vuzix wrap 920 is a video eye wear device primarily made for providing individual big screen movie experience. 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. It has a controller which takes in the input and provide the video for the goggles to display.

Figure 2.1: Vuzix video eye wear

2.1.2 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 [4]. The device is priced at a very low 35$. The Raspberry Pi Foundation, which is the brain behind the device released Raspbian, at the time its recommended Linux distribution. This made the Raspberry Pi suitable for the application of video processing schemes as with a Linux Distribution ported the prototyping time would drastically reduce.

Figure 2.2: Raspberry Pi

2.1.3 Raspberry Pi camera module

The Raspberry Pi Camera Module is a custom designed add-on for Raspberry Pi. It attaches to Raspberry Pi by way of one of the two small sockets on the board upper surface. This interface uses the dedicated CSI interface, which was designed especially for interfacing to cameras. The CSI bus is capable of extremely high data rates, and it exclusively carries pixel data. The sensor itself has a native resolution of 5 megapixel, and has a fixed focus lens onboard. In terms of still images, the camera is capable of 2592 x 1944 pixel static images, and also supports 1080p30, 720p60 and 640x480p60/90 video [4]. This helps us in getting high frame rate and resolution to work with.

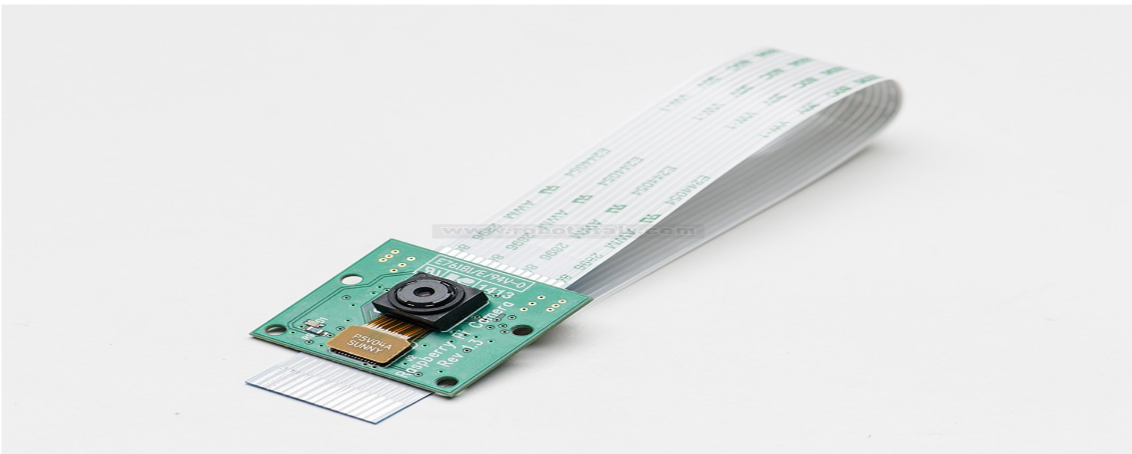

Figure 2.3: Raspberry Pi camera board

2.2 The block diagram

To better understand the function of each module and the basic flow of the device, a block diagram is given below

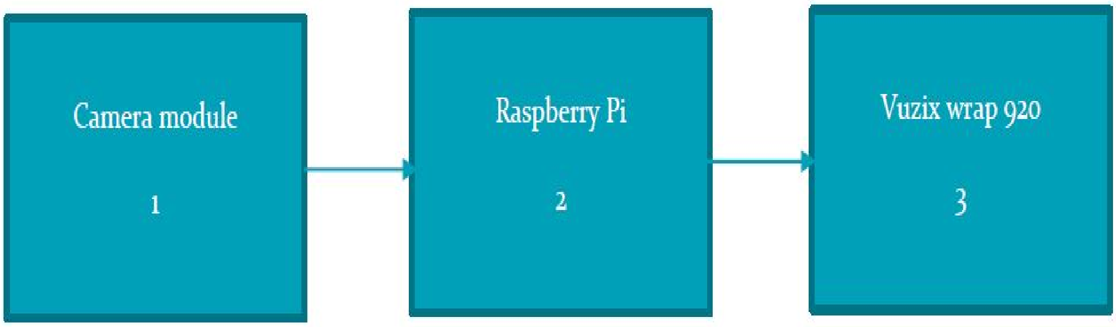

Figure 2.4: The block diagram

1. Get the video feed from the camera and send the frames to Pi.
2. Perform image processing operations and send the processed frames to the Vuzix eye wear through the AV output.
3. Show the recieved frames on the wearable display.

CHAPTER 3

SOFTWARE

3.1 Working with Raspberry Pi

The Raspberry Pi is a credit-card-sized single-board computer developed in the UK by the Raspberry Pi Foundation with the intention of promoting the teaching of basic computer science in schools. The Foundation provides Debian and Arch Linux ARM distributions for download. Tools are available for Python as the main programming language with support for BBC BASIC. I am using an Image of Raspbian, a Debian like distribution specifically for Raspberry Pi. We can download the image directly from the foundation's website.

3.2 Network proxy settings

If we are working under a proxy network, it is necessary to configure the proxy for all the package managers we are going to use. Below are the ways to do this for each one of them.

3.2.1 Setting up environment variables for http_proxy and https_proxy

We can set proxy in raspberry pi by assigning the environment variables http_proxy, https_proxy, ftp_proxy and no_proxy to the appropriate addresses [6]. To apply this settings system wide add the following lines to the file /etc/environment.

```
export http_proxy="http://username:password@host:port"
export https_proxy="https://username:password@host:port"
export ftp_proxy="ftp://username:password@host:port"
```

3.2.2 Setting up proxy for apt-get

Sometimes apt-get doesn't use the environment variables and asks for authentication. We can avoid this by applying proxy settings to it separately. Navigate to etc/apt/apt.conf.d/ folder. Create a file named 10proxy and add the following lines in it.

```
Acquire::http::Proxy 'http://username:password@host:port/';
Acquire::https::Proxy 'https://username:password@host:port/';
Acquire::ftp::Proxy 'ftp://username:password@host:port/';
```

3.2.3 Setting proxy in wget

We will be using wget to install some drivers. Normally wget imports the proxy settings from the environment variables. But sometimes this may not happen. To avoid that we edit the file named “wgetrc” located at /etc/ and add the following lines

use_proxy=yes
http_proxy="http://username:password@host:port"
https_proxy="https://username:password@host:port"
ftp_proxy="ftp://username:password@host:port"

3.3 Downloading and updating software packages on Pi

To install software packages in Raspberry Pi. We can use apt-get or any other Linux package manager. For apt-get

sudo apt-get install <Package-name>

To be able to update the firmware for Raspberry Pi. We need to download a script named “rpi-update”. This helps us to directly upgrade the packages. To install “rpi-update” and run it, please use the following commands

sudo apt-get install rpi-update
sudo rpi-update

In case the above method fails, we can always update the firmware using the following commands

sudo apt-get update
sudo apt-get upgrade

3.4 uv4l driver for Raspberry Pi camera module

The Raspberry Pi camera board is connected to the Pi using a camera serial interface. Since it is not connected using USB, Raspberry Pi doesn't recognize the camera board as a video device. So we need to register the camera in the Pi a video device by the help of a Linux driver called “UV4L”. To install UV4L open a terminal and type the following commands [5]:

$ wget http://www.linux-projects.org/listing/uv4l_repo/lrkey.asc
$ sudo apt-key add ./lrkey.asc

Add the following line to the file /etc/apt/sources.list :

deb http://www.linux-projects.org/listing/uv4l_repo/raspbian/ wheezy main

This two commands will upgrade UV4L to the most recent version, if it's already installed.

$ sudo apt-get update
$ sudo apt-get install uv4l uv4l-raspicam

If you want the driver to be loaded at boot, also install this optional package:

$ sudo apt-get install uv4l-raspicam-extras

Now the UV4L core component and the Video4Linux2 driver for the CSI Camera Board are installed. If you occasionally get unexpected errors from the driver, consider updating the firmware with the following command:

$ sudo rpi-update

After successfully installing the UV4L driver, we need to register the camera board. Open the terminal and type the following commands

$ pkill uv4l
$ uv4l –driver raspicam –auto-video_nr –encoding yuv420 –nopreview
$ export LD_PRELOAD=/usr/lib/uv4l/uv4lext/armv6l/libuv4lext.so

Now that the camera is a video device. It can be used with any video processing package.

3.5 Installing OpenCV and its dependencies

For our image processing operations, we will be using the popular computer vision library "OpenCV". Installing OpenCV on Raspberry Pi is similar to any other Linux system except in this case we have to compile the library for UV4L devices. For this scenario, OpenCV version 2.4.6.1 is recommended as it is a stable working release for V4L devices. To install there are great step by step guides on the internet. One of them which is helpful is given below.

http://jayrambhia.wordpress.com/2012/06/20/install-opencv-2-4-in-ubuntu-12-04-precise-pangolin/

3.6 The block diagram

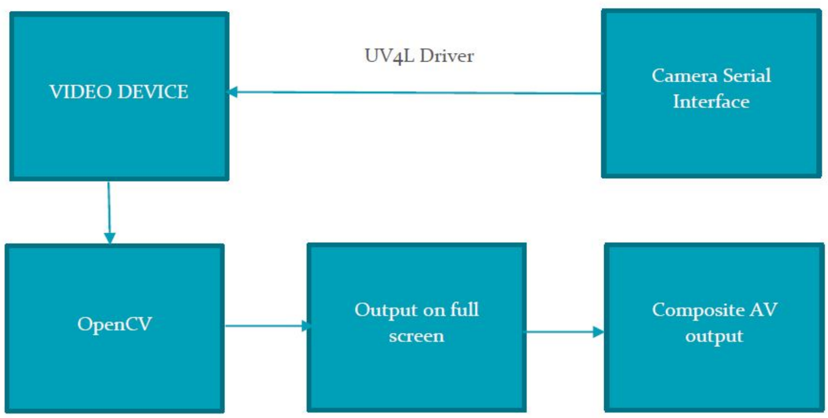

Figure 3.1: Working of the software inside raspberry pi

CHAPTER 4

IMAGE PROCESSING ALGORITHMS

4.1 Digital zoom control

The subjects using our device should be able to view magnified versions of the images on the display. The best way to perform zoom in and zoom out is to Crop the image to our desired level and resize it to the original resolution. To avoid losing detail, bilinear image interpolation is applied. We will discuss the method briefly below.

4.1.1 Bilinear image interpolation

When an image needs to be scaled up, each pixel of the original image needs to be moved in a certain direction based on the scale constant. However, when scaling up an image by a non-integral scale factor, there are pixels (i.e., holes) that are not assigned appropriate pixel values. In this case, those holes should be assigned appropriate RGB or grayscale values so that the output image does not have non-valued pixels. Bilinear interpolation can be used where perfect image transformation with pixel matching is impossible, so that one can calculate and assign appropriate intensity values to pixels. Unlike other interpolation techniques such as nearest neighbor interpolation and bicubic interpolation, bilinear interpolation uses only the 4 nearest pixel values which are located in diagonal directions from a given pixel in order to find the appropriate color intensity values of that pixel. Bilinear interpolation considers the closest 2x2 neighborhood of known pixel values surrounding the unknown pixel's computed location. It then takes a weighted average of these 4 pixels to arrive at its final, interpolated value. The weight on each of the 4 pixel values is based on the computed pixel's distance (in 2D space) from each of the known points [2]. The implementation of bilinear image interpolation is shown below using an example.

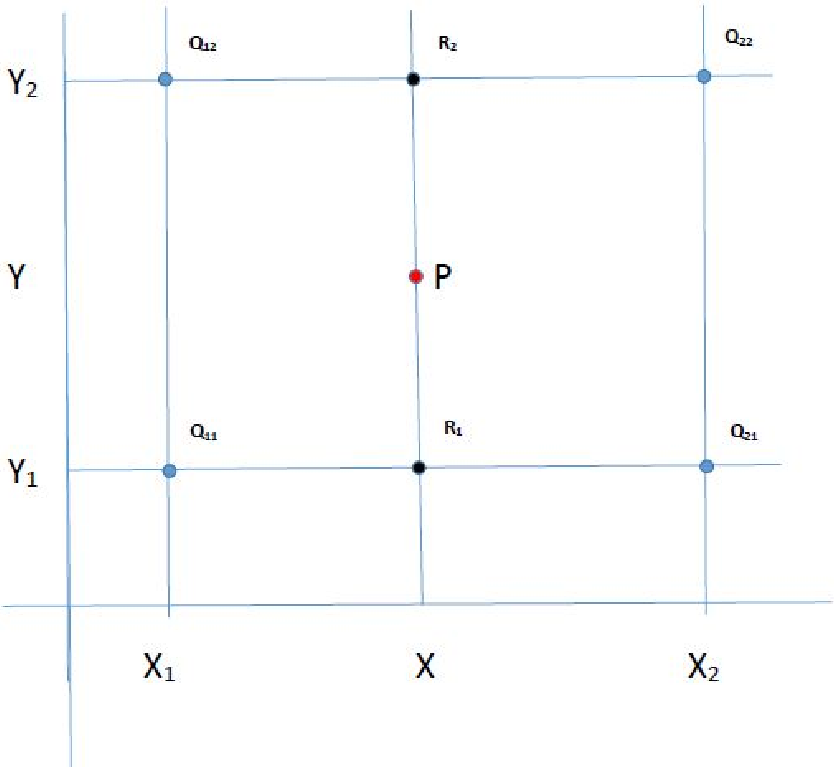

Figure 4.1: Linear interpolation

Suppose that we want to find the value of the unknown function f at point $P = (x, y)$. It is assumed that we know the value of f at the four points $Q_{11} = (x_1, y_1)$, $Q_{12} = (x_1, y_2)$, $Q_{21} = (x_2, y_1)$, $Q_{22} = (x_2, y_2)$.

We first do the linear interpolation in X-direction. This yields

$$f(R_1) = \frac{x_2 - x}{x_2 - x_1} f(Q_{11}) + \frac{x - x_1}{x_2 - x_1} f(Q_{21}) \tag{4.1}$$

where $R_1 = (x, y_1)$

$$f(R_2) = \frac{x_2 - x}{x_2 - x_1} f(Q_{12}) + \frac{x - x_1}{x_2 - x_1} f(Q_{22}) \tag{4.2}$$

where $R_2 = (x, y_2)$.

We proceed by interpolating in the Y-direction.

$$f(P) = \frac{y_2 - y}{y_2 - y_1} f(R_1) + \frac{x - x_1}{x_2 - x_1} f(R_2) \tag{4.3}$$

This gives us the desired estimate of $f(x, y)$.

$$f(x,y) = \frac{1}{(x_2-x_1)(y_2-y_1)}(f(Q_{11})(x_2-x)(y_2-y) + f(Q_{21})(x-x_1)(y_2-y) +$$

$$f(Q_{12})(x_2-x)(y-y_1) + f(Q_{22})(x-x_1)(y-y_1)) \quad (4.4)$$

4.2 Contrast control

Contrast is the difference in luminance and/or color that makes an object (or its representation in an image or display) distinguishable. In visual perception of the real world, contrast is determined by the difference in the color and brightness of the object and other objects within the same field of view [3]. Because the human visual system is more sensitive to contrast than absolute luminance, we can perceive the world similarly regardless of the huge changes in illumination over the day or from place to place. The maximum contrast of an image is the contrast ratio or dynamic range. Given an Image I, we can change the contrast of it by simple addition and multiplication operations.

$$I(p) = \alpha f(p) + \beta \quad (4.5)$$

- α is a multiplication factor and β is a number less than 255.
- When the changed value of the pixel exceeds 255 , it is assigned 255.
- In case one of the factors is negative , the negative pixel values are assigned 0.

4.3 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 [1]. 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. 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. Let f be a given image represented as a m rows by n columns matrix of integer pixel intensities ranging from 0 to L 1. L is the number of possible intensity values, often 256. Let p denote the normalized histogram off with a bin for each possible intensity. So

$$P(n) = \frac{Number of pixels with intensity 'n'}{total number of pixels}, n = 0, 1, ..I - 1. \quad (4.6)$$

The histogram equalized image g will be defined by

$$g_{i,j} = floor((I-1)\sum_{n=0}^{f_{i,j}} P(n)) \tag{4.7}$$

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

$$T(k) = floor((I-1)\sum_{n=0}^{k} P(n)) \tag{4.8}$$

4.3.1 Results

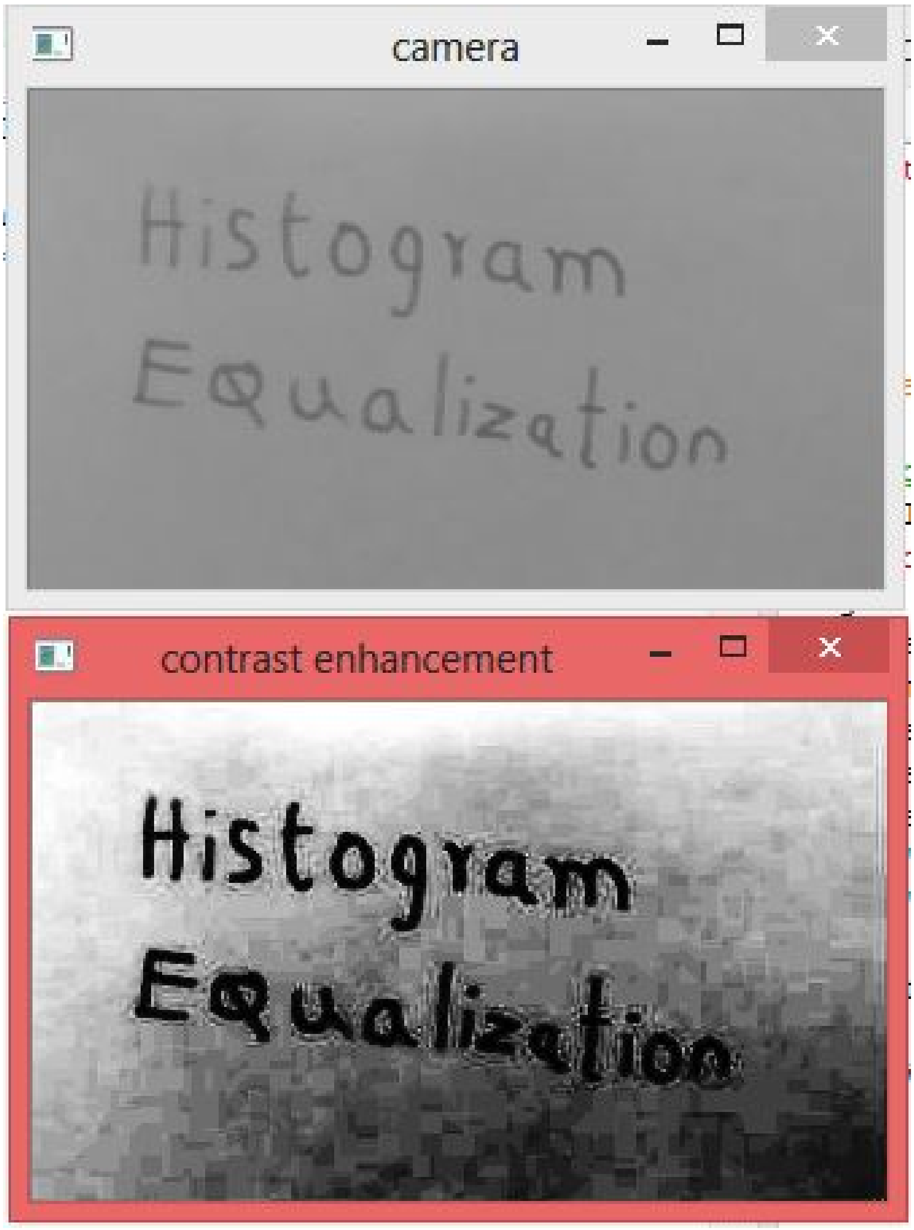

Figure 4.2: Histogram equalization applied on a poor contrast whiteboard image

CHAPTER 5

THE DEVICE

Now that we have all the hardware and the software required, we have to put all the components together to make the actual device. Before moving to prototyping, we need to take care of some aspects. They are discussed in detail below.

5.1 Getting all the components together

5.1.1 GPIO

We have to design tha main controller for the device. This controller will be able to magnify, change the contrast and apply contrast enhancement upon user inputs. We can use the General Purpose Input/Output (GPIO) port on the Pi for this. Raspberry Pi has 8 GPIO ports, a 3.3V supply and a Ground. We will discuss a method by which we can interface switches and buttons. Below is the Raspberry Pi GPIO pinout.

3.3V	1	2	5V
I2C0 SDA	3	4	DNC
I2C0 SCL	5	6	GROUND
GPIO4	7	8	UART TXD
DNC	9	10	UART RXD
GPIO 17	11	12	GPIO 18
GPIO 21	13	14	DNC
GPIO 22	15	16	GPIO 23
DNC	17	18	GPIO 24
SP10 MOSI	19	20	DNC
SP10 MISO	21	22	GPIO 25
SP10 SCLK	23	24	SP10 CE0 N
DNC	25	26	SP10 CE1 N

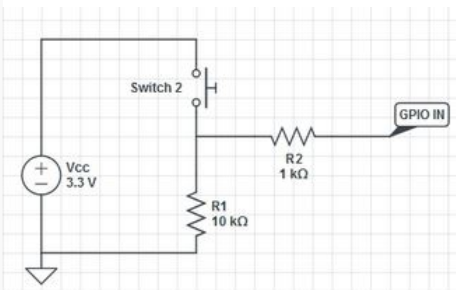

Figure 5.1: Raspberry Pi GPIO pinout

Each control switch or button is connected in the format shown above to its corresponding GPIO pin. The VCC and ground are the pins 1 and 6 respectively. The following is a table which shows the assignment of switches to GPIO pins

GPIO pi number	Associated operation
7 (GPIO 7)	zoom and contrast control
11 (GPIO 17)	Algorithm mode
12 (GPIO 18)	Shutdown button
13 (GPIO 21)	Increase button
15 (GPIO 22)	Decrease button

Table 5.1: GPIO assignment

5.1.2 Power to Vuzix

The Vuzix video eyewear has a controller which powers and provides the video to the displays. The controller has two AA batteries providing 3V to it. However for our device, it becomes difficult to change batteries often because each set of batteries last for maximum of 6 hours. To make the device easy to use and avoid the unnecessary change of batteries each time, it is better to provide the power from Raspberry Pi's VCC(3.3 V). This helped in having a universal power supply for all the components in the device.

5.1.3 Universal power off switch

The whole device receives power from a mobile power bank which has only a reset button. It powers off when no power is being drawn from it. Vuzix controller is designed the same way as the power bank. It powers off automatically when no video is received. So to avoid disconnecting the wires each time, an universal power off switch was designed which cuts the power from the power bank directly.

5.2 The Device

The device was prototyped using a hard cardboard box in which all the components were arranged properly. A handheld controller is externally connected to the box using Velcro strip. Slits are provided wherever there are switches and ports. There are slits for USB and HDMI ports of the Raspberry Pi which help us debug the device without opening it. After proper packaging, the device look like this

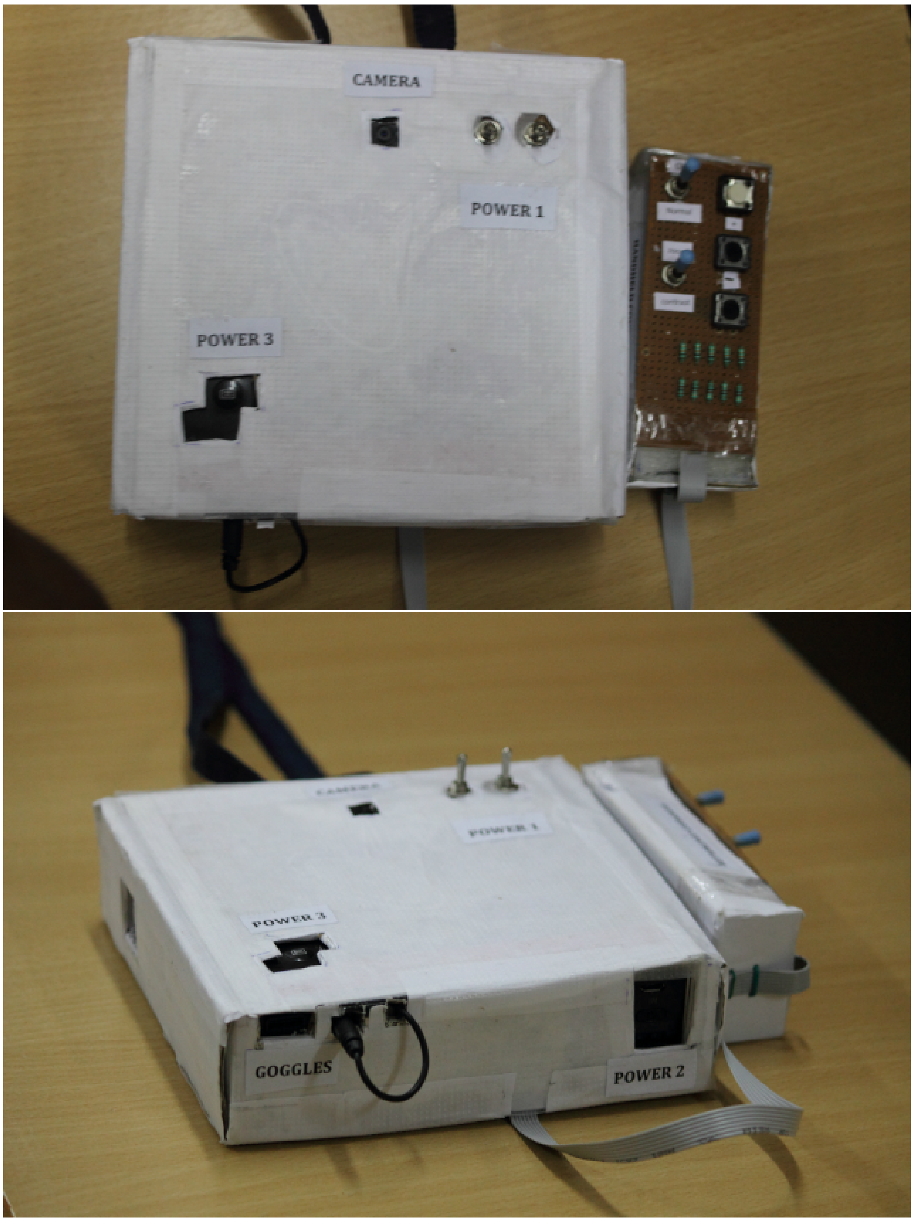

Figure 5.2: The final device

5.3 Working

The device comprises of the following components.

1. The camera device
2. Vuzix electronic goggles
3. Handheld controller
4. A neck cord
5. A USB charger

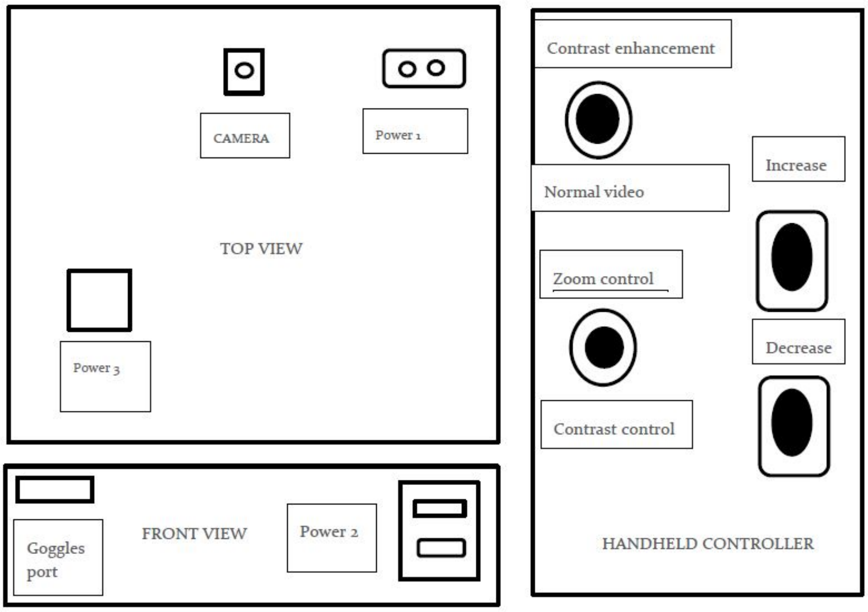

Figure 5.3: Components and switches

5.3.1 Switching the device ON

- Connect the electronic goggles in the port named “Vuzix”.
- Switch on the device in the following sequence.

1. Switch both the switches on labelled “Power 1”.
2. Press the “Power 2” button, a blue light will glow.
3. Press the “Power 3” button, a blue light will glow.

Following the above steps switches the device ON and the Raspberry Pi starts up booting. After a few seconds we will be able to a screen with the video capture.

5.3.2 Using the device

- Wear the goggles by adjusting the nose rest provided.
- Carefully wear the device by the neck cord provided.
- There are 4 switches in the controller.

1. Mode selector switch (the top left switch) selects Contrast enhancement mode when flipped vertically upward and Normal video when flipped downward.
2. Zoom and contrast control switch (bottom left) allows us to change zoom level when flipped upward and contrast level when flipped downward.
3. Increase button (top right) is used to increase zoom or contrast levels.
4. Decrease button (bottom right) is used to decrease zoom or contrast levels.

5.3.3 Switching the device OFF

To power off the device flip the switch duo labelled “Power 1” beside the camera downward. The power supply will automatically turn off after a few seconds.

CHAPTER 6

TESTING AND RESULTS

The prototype was tested on 5 patients at low vision clinic, Sankara Nethralaya. The test was conducted using the letter charts, blackboard and whiteboard.

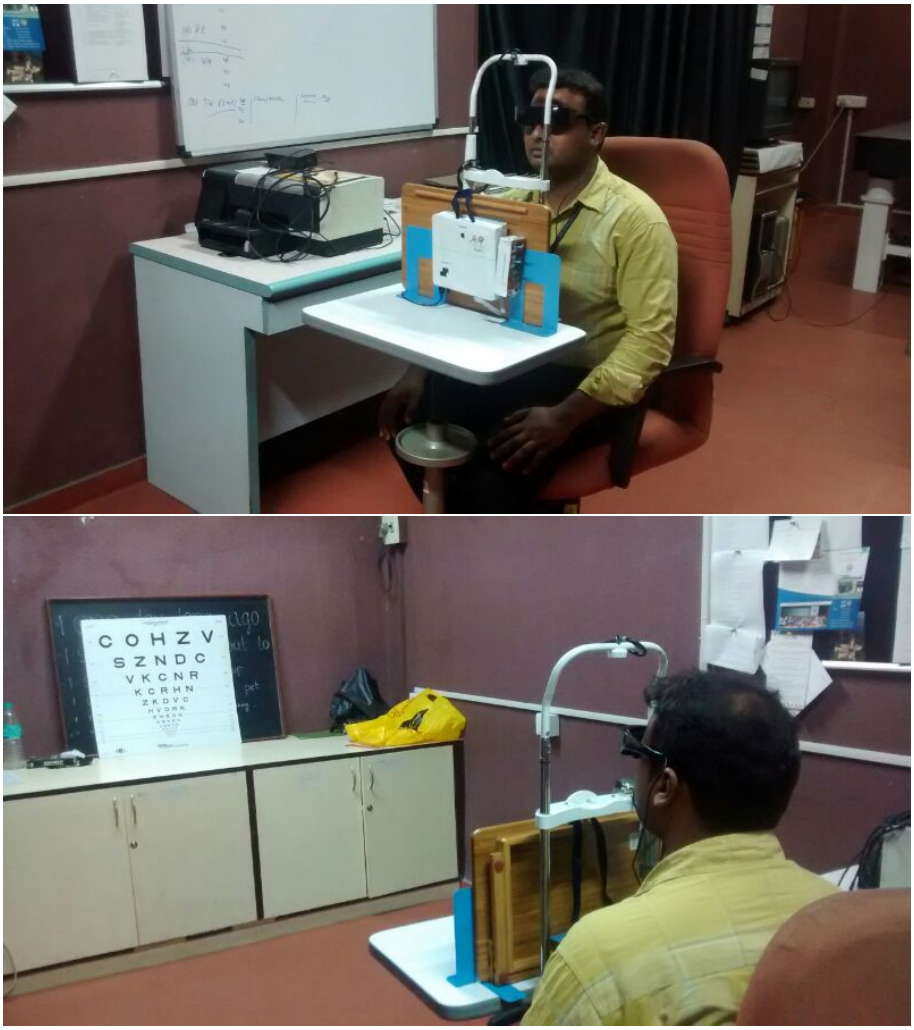

Figure 6.1: Device being tested on Low Vision subject

6.1 Subject 1

Age	24 years
Gender	Male
Pathological Condition	X linked Juvenile retinoschisis
Right Eye (OD)	+1.50 / 2.00 x 90
Left Eye (OS)	+7.00 / 3.50 x 90
Unaided Vision	OD-6/36, OS-Finger counting at 2 meters
Best corrected visual acuity	OD-6/18, OS-Finger counting at 2 meters
Unaided with LVT	OD-6/12 (Using both zoom and contrast), OS-No Improvement
Aided with LVT	Not tested
Contrast Enhancement	The patient found it very helpful while watching the blackboard
Notes	The patient's condition is Hereditary

Table 6.1: Subject 1

6.2 Subject 2

Age	24 years
Gender	Female
Pathological Condition	Hypermyopia, Nystagmus (Both eyes)
Right Eye (OD)	-11.00 / -1.00 x 20
Left Eye (OS)	-11.50 / -1.50 x 160
Unaided Vision	NA
Best corrected visual acuity	OD-1/38, OS-6/60
Unaided with LVT	No Improvement
Aided with LVT	OD-4/25, OS-4/16, OU-4/18
Contrast Enhancement	The patient found it slightly helpful while watching the blackboard
Notes	Patient complained about brightness and contrast

Table 6.2: Subject 2

6.3 Subject 3

Age	24 years
Gender	Male
Pathological Condition	Hyper myopia
Right Eye (OD)	-9.00 / -2.00 x 90
Left Eye (OS)	-8.00 / -1.50 x 90
Unaided Vision	OD-6/36, OS-6/45
Best corrected visual acuity	OD-6/12, OS-6/18
Unaided with LVT	OD-6/24 (Using both zoom and contrast), OS-6/36
Aided with LVT	OD-6/9 (Using both zoom and contrast), OS-6/12
Contrast Enhancement	The patient found it very helpful while watching the blackboard
Notes	The patient complained about the resolution for smaller lines

Table 6.3: Subject 3

6.4 Results and summary

Subjects were regular patients of the low vision clinic at Sankara Nethralaya, Chennai. The results for the prototype testing were very encouraging. Some points from the feedback are discussed below

- All the subjects found the zoom and contrast functions very helpful.
- 3 out of 3 patients found contrast enhancement very useful while reading the blackboard and the whiteboard.
- The common feedback from the patients was about the resolution. Vuzix offers only 640x480 viewing resolution and after a certain magnification the text becomes blurry.

CHAPTER 7

FUTURE SCOPE OF WORK

In this project, we tried to help low vision subjects by enhancing their viewing experience. We used a digital wearable display in conjunction with a Raspberry Pi computer and a Camera to facilitate real time image processing. From the results, it is evident that the device has the potential to make the lives of people with low vision much easier and better. The device can be wore by students for viewing blackboard in a classroom, while reading and many other scenarios. However, to materialize this prototype into a product there are some issues which needs to be solved.

7.1 Installing the camera on display goggles

We did the testing stationarily by mounting the device on an adjustable apparatus. I reality, the camera must be on the goggles. We need to figure out a way to mount it on the camera.

7.2 Improving resolution

The resolution of 640x480 that we have is not sufficient to provide magnification. After some level of zoom, it stops being helpful and gives us the negative effects. So, the resolution of the goggles must be improved.

7.3 Processing power

The image processing on raspberry pi is not fast and we can notice some lag between the frames. This must be solved for smooth and uninterrupted use of the device.

REFERENCES

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