GazePointer: A Real-Time Mouse Pointer Control Implementation Based on Eye Gaze Tracking

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Declaration

“No portion of the work referred to in the dissertation has been submitted in support of an application for another degree or qualification of this or any other university/institute or other institution of learning”.

MEMBERS’ SIGNATURES

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It is You we worship and You we ask for help. (Quran, 1:5)

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Abstract

The field of Human-Computer Interaction (HCI) has witnessed a tremendous growth in the past decade. The advent of tablet PCs and cell phones allowing touch-based control has been hailed warmly. The researchers in this field have also explored the potential of ‘eye-gaze’ as a possible means of interaction. Some commercial solutions have already been launched, but they are as yet expensive and offer limited usability. This project strives to develop a low cost real time system for eye-gaze based human-computer interaction.

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Chapter 1

Introduction

1.1 Basic overview

GazePointer is a Human Computer Interaction application using computer vision algorithms for controlling the mouse pointer by calculating a person's Point of Gaze. It explores potential of eye gaze as a pointing device and develop an algorithm based on computer vision techniques, so as to provide a low cost and fully software based solution. Project is developed using MATLAB®, OpenCV and Qt. GazePointer can be extended to Microsoft Windows and Linux OS, and algorithms developed in OpenCV can also be ported to Android and Mac OS.

Idea behind GazePointer was to develop an interface which can enhance user experience of interacting with computer, which detects eye gestures,which detects minute pupil movements and result in pointer movements in accordance with them. GazePointer extracts human visual attention from video frames captured by Web-cam; it performs human eye gesture detection i.e. moving towards right, left, still etc. then uses these results to calculate Point of Gaze. This is achieved by applying computer vision algorithms on the video frames captured by webcam.

This thesis is intended to document the work done in this project and provides in-depth details of project. This thesis is written in LaTeX.

1.2 Background

Eye tracking is the process of measuring eye position and movements. Whereas, eye gaze reflects a person's point of interest, tells where he/she is looking and eye gaze tracking seeks to keep track of person's point of gaze. This project is concerned about gaze tracking rather than eye tracking.

Researchers have been working on conducting studies about eye gaze tracking and developing systems capable of eye gaze based interaction. Many companies also carried research on eye gaze tracking, this led to successful production of proprietary solutions and made them available in market. But they offer only limited usability, involve complex hardware, don't have capacity to provide user friendly human-computer interaction and are very costly, out of reach for domestic users. Some of them are shown in Figure (1.1).

Some of them use IR lighting, complex hardware which make it more difficult to interact with computer. Therefore, it would be exciting to conduct a research study which can lead to introduction of a non-intrusive, software system based on eye gaze tracking, offering user friendly human-computer interaction.

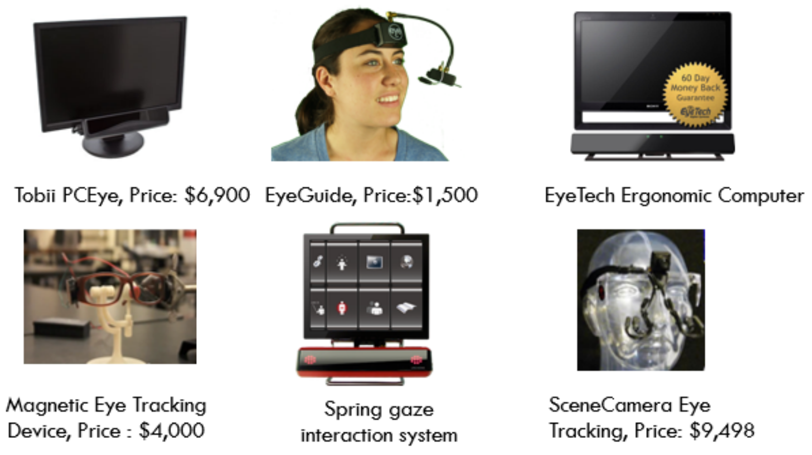

Tobii PCEye, Price: $6,900
EyeGuide, Price:$1,500
EyeTech Ergonomic Computer
Magnetic Eye Tracking Device, Price : $4,000
Spring gaze interaction system
SceneCamera Eye Tracking, Price: $9,498

Figure 1.1: Some available gaze tracking systems [1, 2, 3, 4, 5, 6]

1.3 Goals and Objectives

Project undertakes to develop a system which will only use webcam, to use human eyes as a pointing device for computer system and provide user friendly human-computer interaction. Project objectives are outlined below:

- Face & Eyes Detection
- Finding Center of Iris/Pupil
- Eye Corners Extraction
- Develop an algorithm to calculate Point of Gaze based on Eye features found.
- Develop a GUI to show results.
- Develop a simple Calibration technique.

1.4 Method

First of all, problem statement was defined, ‘design and implement an algorithm to provide human-computer interaction based on eye gaze tracking, which will need only Webcam and PC’. After literature study, some possible solutions were discussed, their drawbacks and their plus points were observed, resulting in a basic algorithm which was revised during implementation. Some techniques related to face and eyes detection were studied during literature study, also obtained information about algorithms for facial & eyes features extraction.

Project can be discussed in two parts:

Features Detection: Detect and keep track of facial and eyes features, adequate for gaze projection.

Gaze Projection: Use detected features to calculate Point of Gaze and track it.

1.5 Thesis Outline

This section gives outline of thesis, documenting a brief introduction of all chapters.

Chapter2 gives an overview of previous work done in this field and attempts to identify problems in existing gaze tracking solutions.

Chapter3 describes the basic framework for implementation of eye gaze tracking based human computer interaction application. The chapter introduces with different steps involved in algorithm implementation.

Chapter4 is a collection of different tasks performed for eye gaze tracking algorithm implementation using MATLAB® coding. It contains different sections, each one of them will explain the implementation of a module.

Section4.2 presents a detailed overview of algorithm, used for face and eyes detection. Face detection algorithm is a two-step approach, first the algorithm acquires face candidates and second step involves facial features detection to verify the face candidates. Where eyes were detected from the eye maps derived from the luma and chroma components of the image.

Section4.3 describes Center of Iris/Pupil detection algorithm. Pupil detection algorithm is based on Hough Circular Transform method. Images are firstly pre-processed to reduce false detections, passed through edge detection filter and then Circle detection algorithm is applied.

Section4.4 contains a detailed discussion about incomplete work done on Gaze estimation under this project.

Chapter5 is devoted to explain algorithm implementation using OpenCV library. This chapter is also divided into sections, each one of them attempts to give details of one stage of algorithm.

Section5.2 documents the face and eyes detection using OpenCV. OpenCV library provides face and eyes detection utility based on Viola & Jones object detection algorithm and uses Haar classifier approach.

Section5.3 is committed to report pupil detection using OpenCV. Hough Circular Transform is being used for pupil detection.

Section5.4 describes eye corners extraction using OpenCV library. It gives a brief overview of different techniques which were tried for eye corners extraction but could not result in satisfactory results. A detailed discussion about Template Matching technique for eye corners extraction is also available in this section.

Section5.5 is dedicated to point of gaze calculation algorithm for pre-recorded frames. This section gives an insight of algorithm and seeks to illustrate the algorithm with help of figures and equations.

Section5.6 explains the point of gaze calculation algorithm for live stream of frames coming from webcam. Different steps of algorithm are explained in this section.

Chapter6 contains a detailed overview of Graphical User Interface (GUI) designing using Qt SDK. It also gives an in-depth overview of GUI design being used for this project.

Chapter7 is devoted to evaluation of different modules of this project. It attempts to quantify the accuracy of algorithm.

Chapter8 gives final words of conclusion and suggests improvements and enhancements to algorithm, which can help new researchers in this field.

Chapter 2

LITERATURE REVIEW

Many computing devices come already with built-in cameras, such as mobile phones, laptops, and displays. Processor power still increases steadily and standard processors are powerful enough to process the video stream necessary to perform eye-gaze tracking, at least on desktop and laptop computers. Some people interact with the computer all day long, for their work and in their leisure time. As most interaction is done with keyboard and mouse, both using the hands, some people suffer from overstressing particular parts of their hands, typically causing a carpal tunnel syndrome. With a vision of ubiquitous computing, the amount of interaction with computers will increase and we are in need of interaction techniques which do not cause physical problems. The eyes are a good candidate because they move anyway when interacting with computers. Using the information lying in the eye movements could save some interaction, in particular head-based interaction [7] .

A literature study was conducted before start working on algorithm designing and implementation, to learn about existing systems. This chapter is discussing some of such existing systems which are already developed, their pros and cons are being discussed briefly.

2.1 Eye gaze tracking using Head Mount

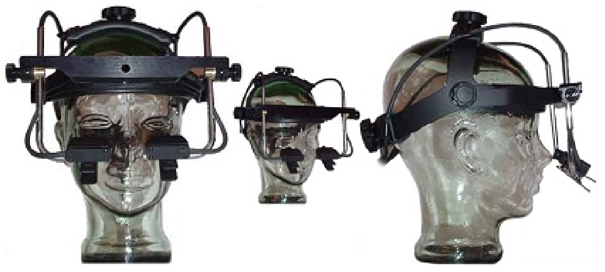


Figure 2.1: Eye Gaze Tracking using Head Mount

Eye gaze tracking is done through a complex hardware component. As it is shown in Figure (2.1), head mounted hardware is required for eye gaze tracking. It becomes difficult for user to use such gigantic equipment. Moreover, a basic problem is the maintenance of such a complicated device. They follow the technique that uses electrodes to predict the eyeball movements. Such equipment can be even harmful for human beings.

2.2 Tobii PCEye

Tobii PCEye is also controlling PC through eyes. Though, it is easy to use, portable and gives accurate tracking, but its expensiveness (As it costs $6,900) makes it not easily available to all users belonging to different economic backgrounds.

Due to high cost such equipment have limited access. The technique used in this thesis provides a low cost solution to eye gaze tracking, which can be easily available to all, because of its fully software implementation and it is low cost.

Figure 2.2: Tobii PCEye

2.3 Eye Glasses

Another device used for eye gaze tracking is eye glasses or data glasses. To calculate the eye gaze, eyes are lightened with infrared light using light emitting diodes (LEDs). In combination with it a camera takes the position of the eyes and computer calculates the point of gaze. The reflections of infrared light are determined in iris, through the image taken by the camera. It is detected through differences in the brightness due to reflection in the eye. Finally, various algorithms are used to calculate the point if gaze.

Using such a device around the head can cause discomfort for the user. Moreover, use of LEDs can be harmful for human eye.

Figure 2.3: Eye Glasses

2.4 SceneCamera Eye Tracking

SceneCamera eye tracking device is an application which controls motion of mouse pointer through eyes movements. It records user's eye position from the real-time video being extracted. At the back end software algorithm runs which saves the eye positioning and the real-time video in computer hard drive. After this a calibration technique is applied which processes the mouse pointer movement.

This apparatus costs $9,498. Moreover, it consists of a complicated hardware structure. Such things make this technology uncomfortable and out of reach for customers. The devices which are not head-mounted are easy to use and little calibration is required for them.

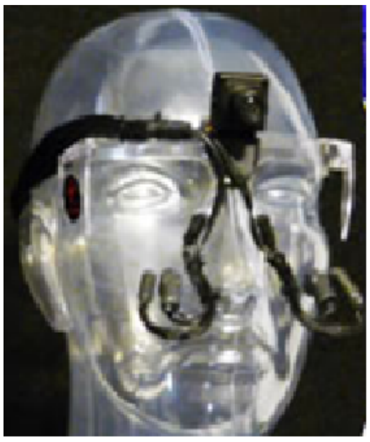


Figure 2.4: SceneCamera Eye Tracking Device

2.5 Eye Gaze Tracking Applications

Eye gaze tracking research is entering its fourth era, distinguished by the emergence of interactive applications in various fields, covering Neuroscience, psychology, industry, marketing, computer science etc. Some applications of Eye gaze tracking are discussed below.

2.5.1 Neuroscience

Eye Movements and Brain Imaging

Recently, eye movement recording and functional brain imaging have been used to track a subject's fixation point while simultaneously recording cortical activation during attentional tasks, in order to identify functional brain structures implicated in attentional behavior. Presently, possibly due to prohibitive cost, combined Eye gaze tracking and brain imaging equipment are not in widespread use, although such devices are beginning to appear [8, 9, 10].

2.5.2 Psychology

Reading

Rayner (1998) synthesizes over 100 years of research. While the reader is referred to Rayner's article. When reading English, eye fixations last about 200-250 ms and the mean saccade size is 7-9 letter spaces. Eye movements are influenced by textual and typographical variables, e.g., as text becomes conceptually more difficult, fixation duration increases and saccade length decreases.

Factors such as the quality of print, line length, and letter spacing influence eye movements. Eye movements differ somewhat when reading silently from reading aloud: mean fixation durations are longer when reading aloud or while listening to a voice reading the same text than in silent reading [8, 9, 10].

2.5.3 Industrial Applications

Aviation

An example of a recent combined use of relatively new Eye gaze tracking technology in a sophisticated flight simulator was reported by Anders (2001). Eye and head movements of professional pilots were recorded under realistic flight conditions in an investigation of human-machine interaction behavior relevant to information selection and management as well as situation and mode awareness in a modern glass cock-pit. Analysis of eye movements illustrates the importance of the Primary Flight Display (PFD) as the primary source of information during flight (the PFD is the familiar combined artificial horizon and altimeter display for combined altitude and attitude awareness). As a proof of concept, this study shows the potential of eye movements for judgment of pilots performance and future training of novice pilots [8, 9, 10].

Driving

It is widely accepted that deficiencies in visual attention are responsible for a large proportion of road traffic accidents (Chapman & Underwood, 1998). Eye movement recording and analysis provide important techniques for understanding the nature of the driving task and are important for developing driver training strategies and accident countermeasures [8, 9, 10].

Experienced drivers obtain visual information from two sections of their view of the road ahead, in order to maintain a correct position in lane whilst steering their vehicle around a curve. The more distant of these two sections is used to predict the road's future curvature. This section is optimally 0.75-1.00 s ahead of the driver and is used by a feed-forward (anticipatory) mechanism which allows the driver to match the curvature of the road ahead. The other, nearer, section is about 0.5 s ahead of the driver and is used by a feedback (reactive) mechanism to 'fine tune' the driver's position in lane. Eye gaze tracking experiments have shown that the feedback mechanism is present in most people regardless of their driving experience (although its accuracy is higher in those with experience), but that the feed-forward mechanism is learned through experience of steering tasks (that can include riding a bicycle, computer driving games, etc.) [8, 9, 10].

2.5.4 Marketing/Advertising

Eye gaze tracking can aid in the assessment of ad effectiveness in such applications as copy testing in print, images, video, or graphics, and in disclosure research involving perception of fine print within print media and within television displays. Eye gaze tracking can provide insight into how the consumer disperses visual attention over different forms of advertising [8, 9, 10].

Copy Testing

A particularly good example of analysis of eye movements over advertisements in the Yellow Pages TM is given by Lohse (1997). In this experiment, eye movement data is collected while consumers chose businesses from telephone directories. The study addresses (1) what particular features cause people to notice an ad, (2) whether people view ads in any particular order, and (3) how viewing time varies as a function of particular ad features. Eye movement analysis revealed that, consistent with previous findings, ad size, graphics, color, and copy all influence attention to advertisements [8, 9, 10].

2.5.5 Computer Science

Selective Systems

Interactive uses of eye gaze trackers typically employ gaze as a pointing modality, e.g. using gaze in a similar manner to a mouse pointer. Prominent applications involve selection of interface items (menus, buttons, etc.), as well as selection of objects or areas in Virtual Reality (VR). A prototypical application of gaze as an interactive modality is eye typing, particularly for handicapped users [8, 9, 10].

2.5.6 Conclusion

As the present review demonstrates, eye gaze trackers have traditionally shown themselves to be valuable in diagnostic studies of reading and other information processing tasks. The diagnostic use of an eye tracker, as exemplified by the research reviewed here, can be considered the eye trackers mainstay application at the present time and probably in its near future [8, 9, 10].

In this project some advancements in previous available systems are made, which will only use webcam on computer system to interface with the human eyes and also make gaze tracking user friendly. Solution to gaze tracking will be low cost, so that it can have access to everyone. Moreover, eye gaze tracking is based on software solutions, no hardware components are involved as particular. This increases its chances of usage. It is easy to use, handle and interact. No complex hardware is required to make user familiar with it than to proceed rather a user friendly known built-in camera of a laptop is required. The available proprietary solutions are very expensive and they involve complex hardware. In this thesis a low cost and a software based solution is provided.

Chapter 3

Framework

This chapter purports to explain the basic framework for implementation of algorithm. It intends to identify different modules of framework and will give their brief overview. This chapter will serve to answer following questions:

- How will this problem be solved?
- What will be system limitations?
- Which features will be necessary and sufficient to calculate Point of Gaze?

3.1 Concept of Eye Gaze Tracking

An illustration of setup is given in figure (3.1). A user is looking at computer screen and at the same time webcam is capturing live stream. The idea is to enable computer system to manipulate eye gaze by detecting important feature points and combining those features in a way which can result in useful information to calculate user's point of interest.

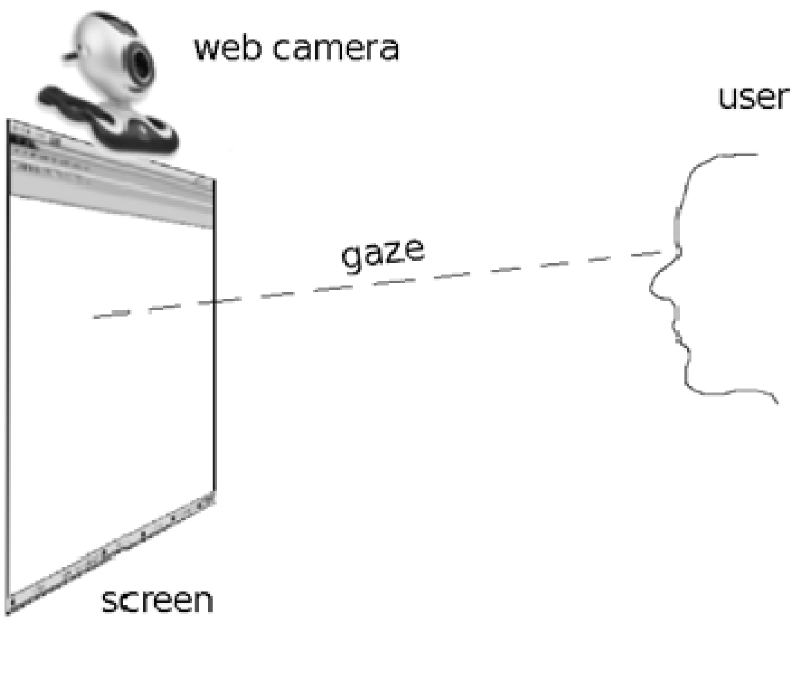


Figure 3.1: An illustration of Setup for Eye Gaze Tracking [11]

Basic concept of eye gaze tracking and framework implemented in this project is being explained using following points:

- Determine facial features which are necessary and sufficient for eye gaze tracking.
- Detecting and tracking these features points in live feed coming web-cam.
- Using these features in a way to extract user's point of interest.
- Track user's point of interest.

3.1.1 System Limitations

While implementing the system, some limitations have to be applied on the system to achieve good performance. The user head should be more or less at the same altitude as the web-cam. The user should be sitting in the center of screen, which is normally the case, user is most of the time sitting in center of screen. The distance between user's eyes and web-cam should be in the range of 20 – 75 cm. Unfortunately due of Hough Circle Transform algorithm for Pupil detection, user can't use the system with eye glasses. The lighting conditions should be good. Ideal situation will be with light pointing at user face and no light at backside of user, light coming from backside will result into shadows and will diminish image quality.

3.2 Facial Features

Literature study and experimentation during implementation helped in finalizing facial features which will be necessary and sufficient to calculate Point of Gaze. A brief overview explaining how these features will be helpful and how they will be found is given below.

Face: Face is an important feature in human, and it is useful in minimizing candidates for eyes during eye patch extraction.

Eyes: Eyes are gist of this idea of eye gaze tracking. To find other feature points in eyes, eye patch must be extracted.

Center of Iris/Pupil: Pupil tells about a person's point of interest. It is being detected using Hough Circle Transform.

Eye Corners: Eye corners act as important feature points as they can be used to extract useful information about eyes i.e. center of eye, eye width, eye height. Eye Corners are being extracted using Template Matching technique.

3.3 Methodology

Algorithm overview is shown in Figure (3.2). It gives an outline of different stages involved between frame capturing by web-cam and movement of pointer in accordance with user's eye gaze.

Image Acquisition: A web-cam is required to acquire images. System will start with image acquisition using an integrated web-cam or USB web-cam.

Image Preprocessing: Preprocessing the data is always helpful in extracting useful information. Images acquired by web-cam must be converted into appropriate formats required by different algorithm at next stages.

Facial Features Detection: It is preliminary step for eyes detection. MATLAB® implementation for face detection is described in Chapter 4, and OpenCV implementation in Chapter 5.

Eyes Features Detection: Necessary eye features were identified and different methods for their implementation were tried, finally HCT yielded satisfactory results for pupil detection and Template Matching technique proved helpful for eye corners detection. These techniques are described in Chapter 4 and Chapter 5.

Point of Gaze Calculation: A mathematical calculations based algorithm was designed to calculate PoG based on found feature points. Algorithm is described in Chapter 5.

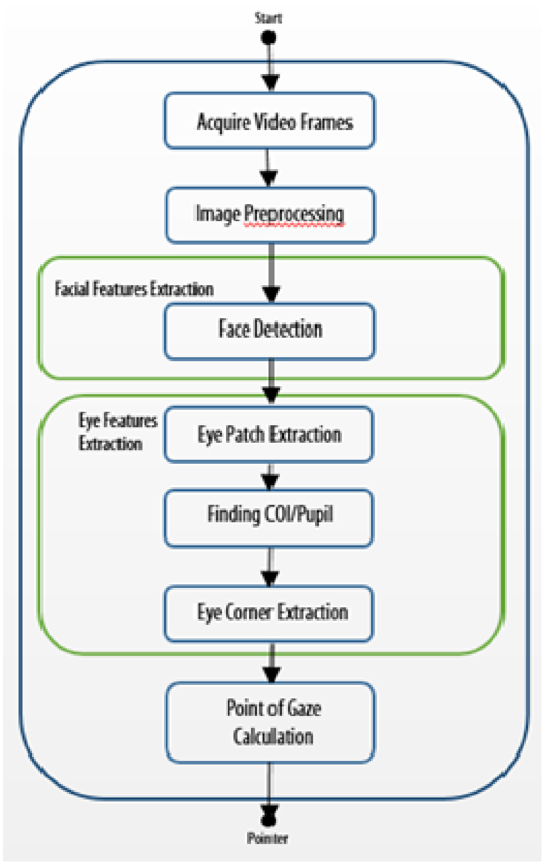


Figure 3.2: System Flow Diagram

Chapter 4

Algorithm Implementation using MATLAB®

4.1 Introductory Task for Gaze Projection

Basic calculations always aid to take a better start, help to answer questions, which restrain us to begin. Before start working on algorithm implementation for face and eyes detection we performed some prefatorial experimentation. Some prefatorial experimentation was performed to answer basic questions like:

- Can a web-cam capture eye movements?
- What resolution will be necessary and sufficient to catch adequate number of eyes pixels acceptable to perform gaze calculations?
- Each movement should be tracked, what should be the frame rate? so as to allow tracking with tolerable saccades.
- This is a research project, so it is mandatory to have knowledge about challenges, which will be trammeling the development and implementation of algorithm.

For this purpose, a video was recorded with still head and fixed distance, and eye ball movements were captured, a frame is shown in figure (4.1). Then wrote a script in MATLAB® to crop eye patches using a fixed bounding box, some frames are show in figure (4.2), which established the fact that webcam has the potential to capture eye ball movements.

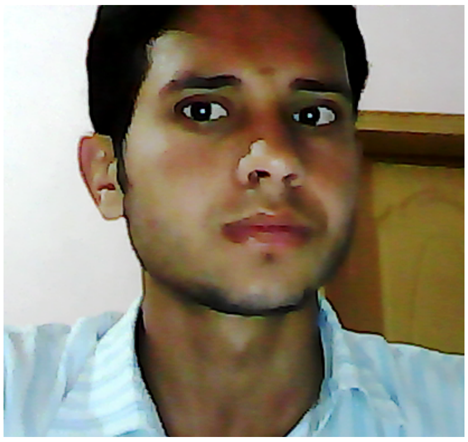


Figure 4.1: A frame from the video sequence captured by web-cam

Here are some parameters that we selected for this video:

- Distance between webcam and eye: 60 cm
- Frame Rate: 15 fps
- Webcam Resolution: 640 X 480

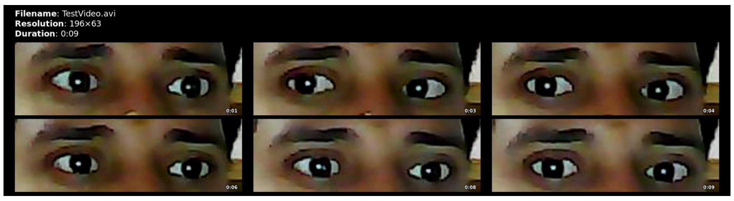


Figure 4.2: Some cropped frames from the video sequence showing eye ball movements

This experimentation ensued to nail down important decisions, which are listed down:

- Webcam has the potential to capture eye ball movements, it should be preferred as a capturing device to make the solution low cost.
- Webcam Resolution of 640 X 480 proved satisfactory.
- Frame Rate of 15 fps is adequate.

4.2 Face Detection

4.2.1 Introduction

GazePointer is a Human Computer Interaction application. Face detection is preliminary step in most of the HCI, video surveillance and face recognition applications. Most of the HCI algorithms assume that face is already detected. Face detection is a classification problem used to classify the image into face and non-face regions. There are lots of techniques available for face detection, some of them are implemented on color images and others require gray scale images as input.

The algorithm described in [12] is based on color images and it uses the skin tone color to acquire face candidates. It proposes to use the YC_bC_r color space for face detection, which is considered to be one of the best approaches in color images.

4.2.2 Overview of Algorithm

Overview of the algorithm is shown in Figure (4.3). It is a two-step approach

1. Acquire face candidates
2. Eyes Detection

Acquired frames are processed through lighting compensation. Lighting compensation technique rectifies the lighting conditions in the images and attempts to normalize the brightness in entire image. These compensated RGB images are non-linearly transformed to the YC_bC_r color space. Skin tone pixels are extracted based on the pixel values in C_r (Chroma) components. Face candidate size can vary in a range of 13x13 box to three fourth of the input frame size. The facial features detection step rejects the face candidates based on the fact that face candidates must have eyes.

4.2.3 Lighting Compensation

Lighting conditions affect the skin tone pixels value that is why they need to be corrected in such a way that lighting variations don't cause much trouble in skin detection. A distinct lighting compensation technique is applied, which uses "reference white" to normalize the color appearance. It takes the top 5% of luma component (Non-linear corrected Gamma component) pixels as reference white if they are at least 100 in number. It regulates the R, G and B components such that reference white pixel values are linearly scaled to 255 in gray scale. The image remains unchanged if adequate number of "reference white" pixels are not found in the image. Lighting compensation technique described in this algorithm results in fewer non-face pixels and more skin-tone facial pixels.

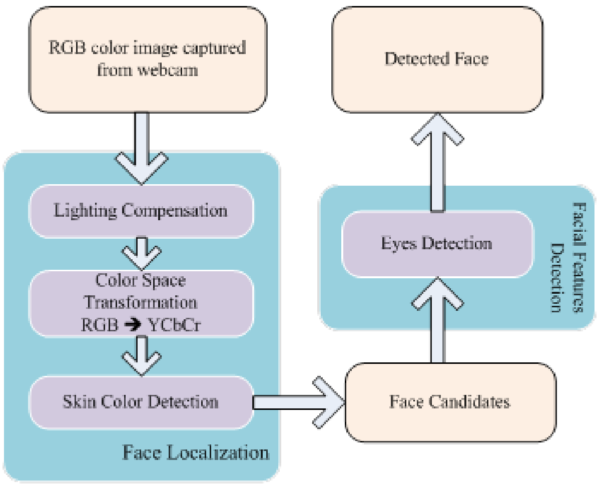


Figure 4.3: Face Detection Algorithm Overview

4.2.4 Color Space Transformation

Extraction of skin-tone pixels requires the appropriate selection of Color Space. [12] States that normalized red-green space is not the best choice for face detection. A comparison of nine different color spaces for face detection is presented in [13], it concluded that tint-saturation-luma (TSL) color space provides best results. [12] suggests to use YC_bC_r color space for face detection, since it is perceptually uniform , is widely used in video compression standards (MPEG and JPEG), and it is similar to TSL color space in terms of separation of luminance and chrominance as well as the skin color block size.

Figure 4.4: Original Image

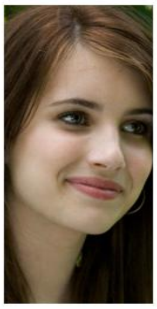


Figure 4.5: Detected Face

4.2.5 Skin Color Detection

Skin tone color nonlinearly depends upon the luma component. Transformed space allows substantial detection of skin-tone colors. More skin-tone pixels were detected with high and low luma in transformed space as compared to the YC_bC_r space. A bounding box was drawn around the detected face from an image (Shown in figure 4.4). MATLAB® function "rectangle" was used to draw bounding box around face. This detected face was cropped using the function "imcrop" for eyes detection stage (Cropped Face is shown in Figure 4.5).

4.3 Eyes Detection

Eyes were detected from the eye maps derived from the luma and chroma components of the image. We build two eye maps from the luma and chroma components and combined them together to acquire the eye map for detected eyes. The chroma eye map depends upon the values of C_b and C_r channels.

Following is the equation to derive the chroma eye map.

$EyeMapC = 1/3[(C_b)^2 + (C_r')^2 + (C_b/C_r)]$

Where C_b, C_r, C_r' are all normalized values in the range [0,255]. Following lines of MATLAB® code describe the technique implemented, to normalize these values.

```
minC_r = min(min(C_r));

maxC_r = max(max(C_r));

C_r = 255 * (C_r - minC_r)/(maxC_r - minC_r);
```

Where the functions "min" and "max" returns the minimum and maximum values respectively.

Morphological operations like dilation and erosion were applied on the luma component of the image to acquire the luma eye map. Dilation is the process of expanding something. In MATLAB®, the built-in function "imdilate" is used for dilation. It uses a structuring element 'SE' to expand an object in the image. Similarly, the built-in function used for erosion is "imerode".

Following MATLAB® statements were used to acquire the luma eye map.

```
SE=strel('disk',4);
UP=imdilate(Y,SE);
DOWN=imerode(Y,SE);
EyeMapL = UP./(DOWN+1);
```

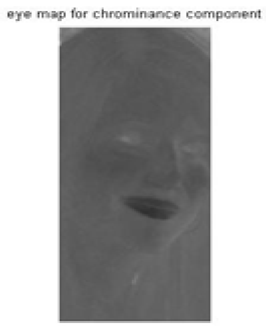


Figure 4.6: EyeMapC

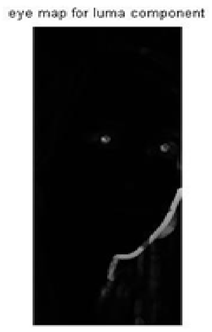


Figure 4.7: EyeMapL

Histogram equalization was applied on the chroma eye map and then combined with the luma eye map using following equation.

$EyeMap = (EyeMapC) AND (EyeMapL)$

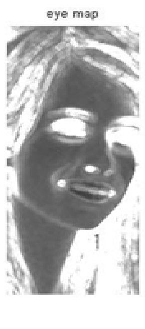


Figure 4.8: EyeMap

This resulting EyeMap was then dilated, masked and normalized to brighten the eyes. Masking was done using a threshold function.

Following commands explain the masking operation on EyeMap.

```
Maxv = max(EyeMap(:));

thresh = maxv-0.5 * Maxv;

imshow(EyeMap > thresh);
```

Only the pixels with greater than threshold value were shown (Figure 4.9).

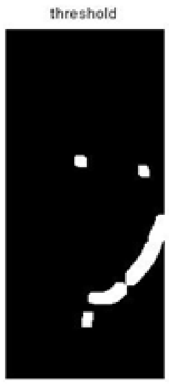


Figure 4.9: Threshold Image

Location of eyes was obtained after the threshold technique. (Figure 4.10)

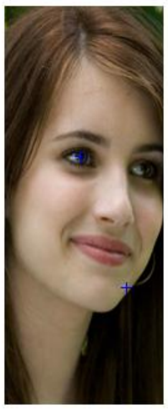


Figure 4.10: Eyes Detected

4.3.1 Drawbacks

This technique was applied to several images of different resolutions and various head postures with different lighting conditions. The drawback in face detection was it detected only Asian faces with wheatish complexion. After observing results, the rate of false detections was more severe in case of eyes detection.

Therefore it was decided to skip these complex and time consuming processes like face and eyes detection, rather use a simple approach for eye patch extraction. It was decided that user will have to fit his/her eyes in a bounding box, in order for eye patch cropping.

4.4 Pupil Detection

Pupil is the central and focusing part of eye, located at center of iris. Light enters into eye through pupil, and finding the position of pupil is principal point of interest in this project. Eye gaze projection is based upon the relative displacement of pupil from center of eye. Pupil needs to be detected to project user's eye gaze on the screen. The first step was to detect the iris from the frames captured with webcam, and then pupil can be found, as it is situated at center of iris.

Iris is the flat, colored and circular part on the white region (Sclera) of an eye. Iris varies in color as black, blue, green etc. As iris is a circular region, so it can be detected using a computer vision technique which can detect circular region. Digital Image Processing is a subject of Computer Vision which is used to extract information from an image. MATLAB® has an Image Processing toolbox, methods from this toolbox can prove helpful in detecting Iris and so Pupil position can be found.

4.4.1 Pupil detection algorithm

Iris is a circular region and can be detected using the very commonly used Hough circular transform technique.The Hough transform is a feature extraction technique used in image analysis, computer vision, and digital image processing. The purpose of the technique is to find imperfect instances of objects within a certain class of shapes.

The classical Hough transform was concerned with the identification of lines in the image, but later the Hough transform has been extended to identifying positions of arbitrary shapes, most commonly circles or ellipses. The Hough transform as it is universally used today was invented by Richard Duda and Peter Hart in 1972, who called it a "generalized Hough transform" after the related 1962 patent of Paul Hough. The transform was popularized in the computer vision community by Dana H. Ballard through a 1981 journal article titled "Generalizing the Hough transform to detect arbitrary shapes".[14]

Hough Circular Transform takes a binary image as an input and detects circle in it. The quality of the image needs to be good to extract every possible information from it. As webcam was not of high resolution i.e. 640x480 (VGA). Therefore, image enhancing techniques were applied to improve the quality of the image. The flow of algorithm is shown in figure (4.11).
Algorithm involves two phases.

1. Image enhancement.

2. Circle detection.

Image Enhancement

Image quality must be improved so that maximum information can be extracted and noise is minimized from it. The frames captured from a webcam are RGB images. An RGB image is a 3 channel image and each channel can have pixel values in a range of 0 to 255. As Hough Circular transform technique takes a binary image as an input, therefore, this 3-channel RGB image was converted to single channel grayscale image using the built-in function in MATLAB® "rgb2gray". A gray scale image is a single channel image and can have pixel values in a range of 0 to 255. A '0' pixel value represents black color and '255' represents white in grayscale.

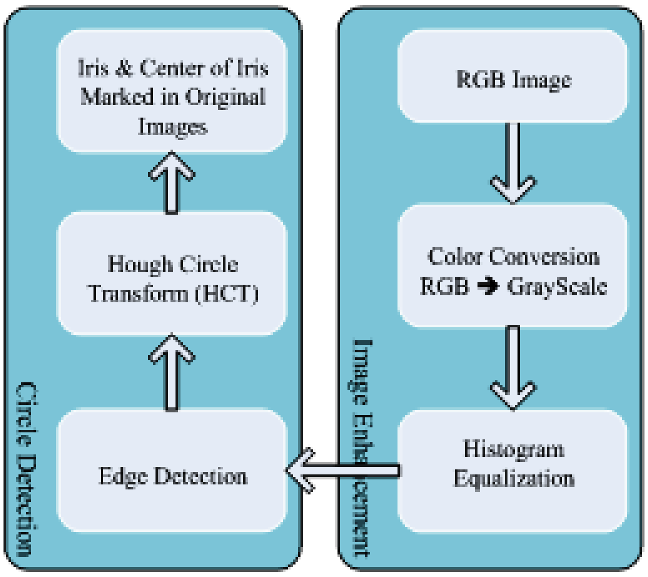

Iris & Center of Iris Marked in Original Images
Hough Circle Transform (HCT)
Edge Detection
Circle Detection
RGB Image
Color Conversion RGB ➔ GrayScale
Histogram Equalization
Image Enhancement

Figure 4.11: Block diagram of Iris detection method

As soon as grayscale image was acquired, histogram equalization was applied for image enhancement. MATLAB® provides implementation of histogram equalization, built-in function "histeq" was used for this purpose. Histogram equalization is used to adjust the contrast of the image.

Circle Detection

"Hough circular transform" is the most widely used technique for circle detection. After enhancing image, next task is the image binarization, because HCT technique takes binary image as an input. Image binarization can be performed using many techniques e.g. Thresholding, adaptive Thresholding, using different edge detection based techniques.

Edge detection based technique was employed in this algorithm for image binarization, MATLAB® built-in function used for this purpose was "edge". This function returns an image which has 1's where it finds edges and 0's elsewhere. An edge in an edged image can be described as a location where an immediate change occurs in the intensities of colors. It finds nothing where constant intensities exist in an input image. MATLAB® has implementation for many edge detection techniques i.e. sobel, canny. "Sobel" edge detector is being used in this algorithm, because it resulted in more accurate detections. The next step was to apply the Hough circular Transform algorithm. It is a mathematical rule that involves circle with a radius 'r'. A new circle drawn with a radius 'r' at the boundary of a previous circle with same radius , will always pass through the center point of the previous circle. The equation of circle is:

$$r^2 = (x - a)^2 + (y - b)^2$$

This equation has three parameters 'r', 'a' and 'b'. Where 'r' is the radius of the circle, 'a' is the center point in x-direction and 'b' is the center point in y-direction.

In an edged image, a circle is drawn of a desired radius for each edge obtained in that image. When enough circles of same radius drawn, intersect at the same point, it is concluded that desired circle of that radius is found at that position.

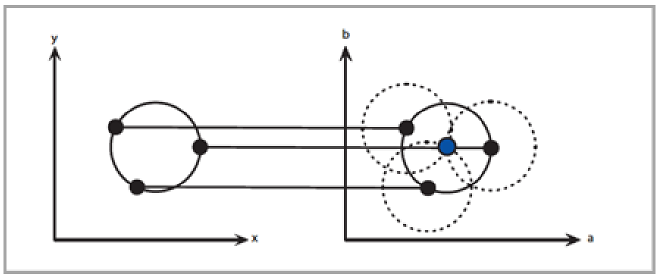


Figure 4.12: Iris Monitoring Window

Following are some steps of HCT algorithm to detect a circle:

- A range of radii was defined. Specific range for iris radius was selected based upon experimentation, and satisfying accuracy rate was achieved using this range.
- Circles for each white pixel of edged image were drawn. This created an accumulative array of circles. A margin was left equal to the radius size, on each extreme end of the rectangular image.
- As the main objective was to find the radius of the curves in the edged image and their center point. Whenever, there were any curves in the edged image, circles were drawn on every point of that curve. Circles matching the radius of that curve were having their center point on the center of that curve.
- Iterated this procedure for each value of radius. Maximum value of each radius was compared with maximum value of other radii, it helped to find other maximum, which was the center of the curve.

4.4.2 Conclusion

Firstly, algorithm was applied on images acquired by a low resolution webcam i.e. 640X480(VGA) and pupil detection accuracy didn't prove satisfactory. As an interesting investigation, algorithm was applied on frames acquired by high resolution webcam i.e. 1280x720(HD 720p) and it resulted in far better detection accuracy, the results were quite accurate, but the processing time per frame was more than expected i.e. 600–700mS. As this project is supposed to be a real-time project, which requires a less computational cost, and it needs to work at least at a frame rate of 15fps, which means complete processing time for each frame should not be more than 66mS. Therefore, it was decided to move on using OpenCV library for algorithm implementation, as the algorithms developed using OpenCV are light weight and have less computational cost.

4.5 Gaze Estimation

Gaze estimation is an interesting research topic, and it can be helpful in improving gaze projections, as it will help the system identifying and rectifying false detections and in affect false gaze projections. It will be an algorithm learning from statistics of usage data and will infer the projection calculations resulting in more projections in areas visited excessively by a user (simply areas of interest of a user) and vice versa.

Objective of this chapter is to discuss work done on the topic under this project. Unfortunately, due to time limitations of this project, this task could not be completed, however, this chapter attempts to cover the completed work and also directs about accomplishment of incomplete work.

Gaze estimation means to learn from usage statistics data and predict the next value of mouse pointer based on probabilities of regions and previous movements of pointer using different algorithms. For the estimation, we started from very basic prediction mechanisms and then gradually developed algorithm using different basic and advanced techniques. These are discussed in gradual steps in different sub-sections of this topic.

4.5.1 Regression to Predict Synthetic Model Motion

"Regression" in statistics is name of careful, informed prediction and estimation. Discussion of regression will concentrate on linear regression. Its basic idea is to find the straight line that "best" fits a set of observed points. Linear regression analysis is a powerful technique used for predicting the unknown value of a variable from the known value of another variable [15].

If x and y are two related variables then the regression analysis can help us to predict values of y for values of x and vice versa. Regression analysis uses the power of polynomial fitting, by making guess of an nth order polynomial based on given data. So, as the pool of data grows, it makes a good guess of polynomial resulting in improved predictions.

Regression analysis is one of the simplest techniques being used for prediction problems. This section is devoted to investigate the potential of regression analysis as a prediction tool. A synthetic model was built for this purpose and the motion of that model was predicted using regression. The task was divided into simple steps:

- A cartoon character was to be selected for synthetic modelling, Lisa was selected [16]. (Shown in figure 4.13)
- A bounding box was fixed around the eyes of cartoon character and co-ordinates x and y were found for center of eyes.
- Eye ball of cartoon character Lisa was moved using some equation (as a linear model) of 1st, 2nd or 3rd order.
- 3rd value was predicted by using previous two actual values.
- When the actual 3rd value was obtained, error was removed in predicted and actual value.

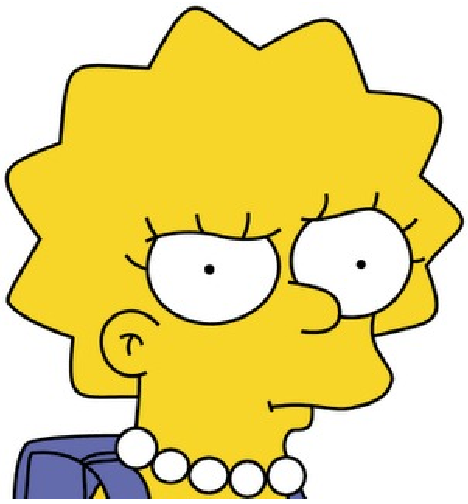


Figure 4.13: Lisa(Cartoon Character Selected)

A MATLAB® program was developed for this task and computed different order regression models for prediction and some conclusions were drawn:

- Nth order Regression model can be used to predict (N - 1)th order equation. The Regression model used to produce best fit after 2 initial wrong predictions.
- Regression can be a useful tool for prediction, if human eye movements follow some equation model, based on prior observation we came to the conclusion that we cannot describe human eye ball movements by any equation model, as they are more or less random, with still and slower movements as well as faster and larger movements.
- After some calculations, it was concluded that regression is not useful for gaze prediction problem and deferred the task to find some relevant filtering or prediction techniques.

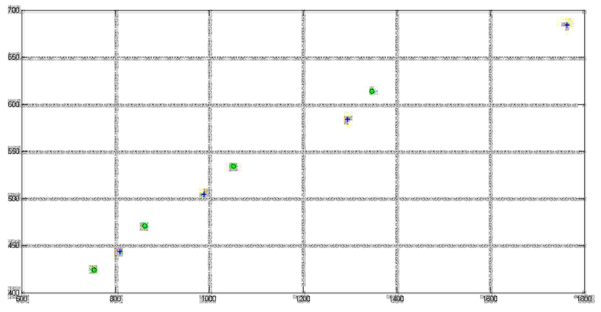


Figure 4.14: 1st order Regression

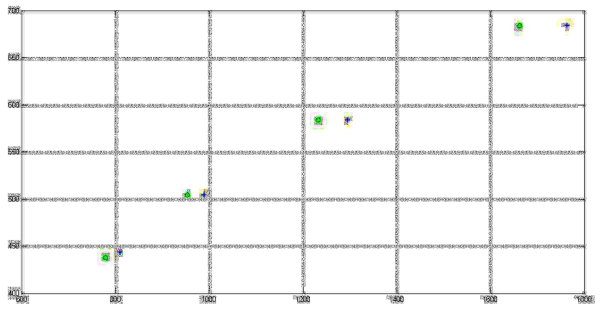


Figure 4.15: 2nd order Regression

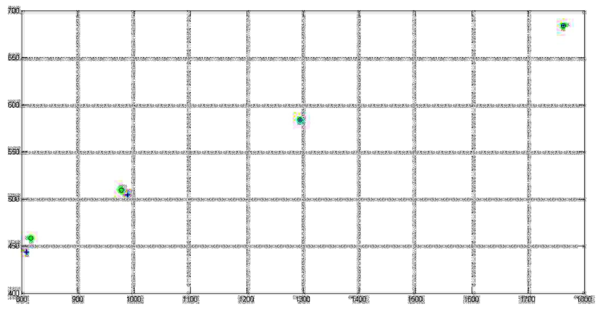


Figure 4.16: 3rd order Regression

Results

Regression was applied on different order equations to predict next values. Outputs of this task are shown in Figures 4.14, 4.15 and 4.16 (actual values: +, predicted values: o).

4.5.2 Project Lisa's Eye movements on Screen

This task had two principal objectives:

1. Apply random walk in two-dimensions on Lisa's eyes.
2. On Screen projection of Lisa's Point of Gaze

Applying Random Walk

First of all the bounding box around Lisa's eyes was fixed, then co-ordinates for center of eyes were calculated. In next step, Random walk was applied to produce random eye ball movements i.e. at each point, there were four possible movements (illustrated in Figure 4.17).

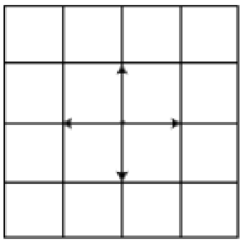


Figure 4.17: Random Walk in Two-dimensions

Iterated this whole process to make a video of eye ball movements of Lisa, some frames of that are shown in Figure (4.18).

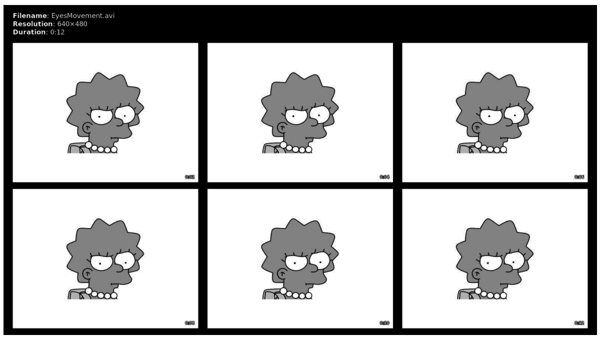


Figure 4.18: Frames from video sequence showing Random walk in Lisa's eyes

On Screen Gaze Projection

A bounding box was drawn around each eye to compute movable area for eye balls. Using the screen resolution and movable area, computation was made that one pixel movement in Lisa's eyes would be equivalent to how many pixels movement on screen, so that Lisa could trace whole screen using eye ball movements.

$\Delta r\ Lisa\ =\ \Delta r\ Screen$

$\Delta\theta Lisa =\ \Delta\theta$ Screen

It was found that one pixel in Lisa's eyes is approximately equal to a rectangle of 9 x 24. As the movement of one pixel results in a rectangle movement of 9 x 24.
Whole procedure was applied iteratively on each frame of video recorded for eye ball movements of Lisa, and recorded a video of the on-screen gaze projections, some frames of video sequence are shown in Figure (4.19).

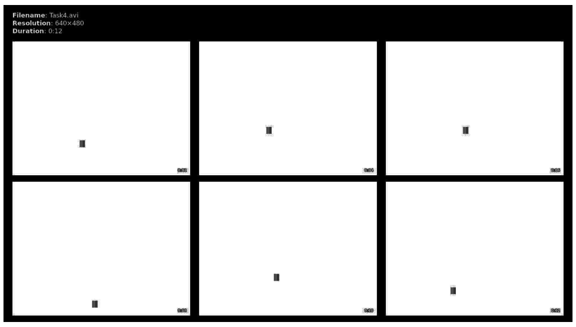


Figure 4.19: Frames from video sequence showing on-screen Gaze Projections

Here is some important data about the whole task:

- Screen Resolution: 640 x 480
- Eye Ball : 6 x 7
- Eye Patch Area: 72 x 27
- Movable area for Eye Ball : 66 x 20
- Rectangle on Screen (corresponding to each pixel of eye) : 9 x 24

4.5.3 Screen Divisions, a Probabilistic Model

Intelligent systems are highly popular nowadays. To make the system intelligent and user friendly, a new concept was introduced of eye gaze system which not only depends upon on-screen gaze projections but also take advantage of user's statistical data, so that final decision about Point of Gaze should be biased towards user's areas of interest on screen.

For this purpose, user interfaces were analyzed for some popular applications and divided the computer screen into 50 regions of different sizes (Regions are shown in figure 4.20). Variable sized region division attempted to accommodate those popular user interfaces.

Applications which influenced the region's partitions include:

- Microsoft office 2007 [17]
- Real Player [18]
- MATLAB® [19]
- Gmail [20]
- Facebook [21]
- Eclipse IDE [22]

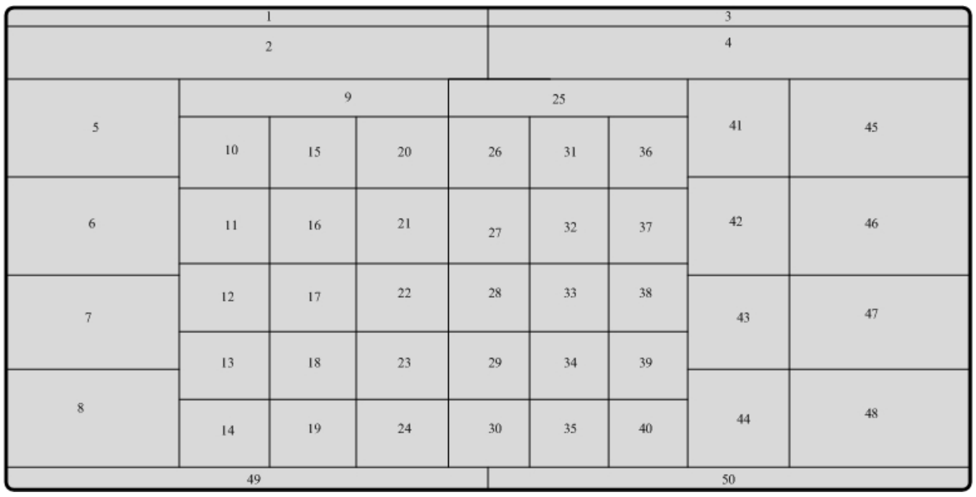


Figure 4.20: Screen Region division

A MATLAB® based program was developed to collect cursor movements data, the program itself records cursor positions at a rate of 15 records per second and then computes region number for each cursor position, and increments the region weight. Method is applied iteratively on each cursor position recorded (Cursor movements data for a 5 minutes recording is shown in Figure 4.21).

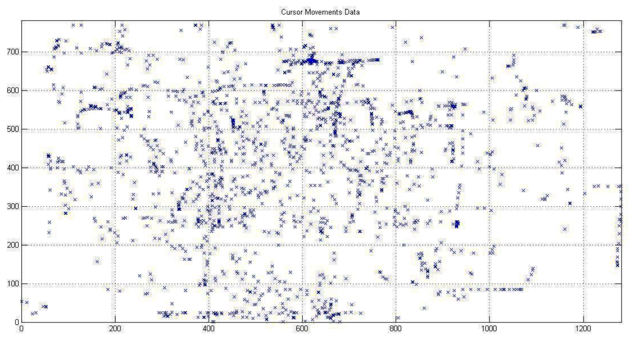


Figure 4.21: Cursor Movements data of a computer user (5 minutes recording)

Finally the program plots a probability mass function of cursor, showing probability of the cursor to be in nth region at a particular time (pmf is shown in Figure 4.22 for data of Figure 4.21).

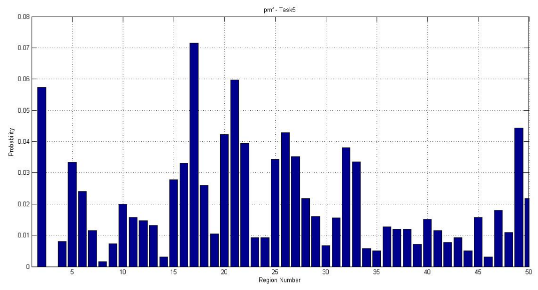
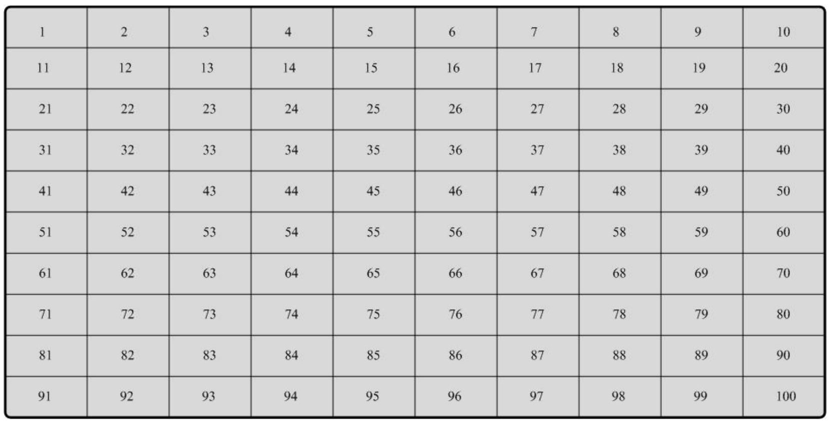


Figure 4.22: Probability Mass Function for data shown in fig 4.21

4.5.4 Improvements in Probabilistic Model

The basic idea about projections is already explained in previous section. On the basis of previous work, slight changes were induced. Uniform region division was adopted instead of variable sized regions (Regions division is shown in Figure 4.23) . This change was introduced to make the task simple and maintain the time constraints.



1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

Figure 4.23: Screen divided into uniform sized regions

Screen resolution of 1280 x 800 was used and divided the screen into 100 Regions. Every Region took the size of 128 x 80. After Regions division, another cursor movement data was collected (Cursor data is show in Figure 4.24) and then based on that data, another Probability Mass Function (pmf) was generated (pmf is shown in Figure 4.25).

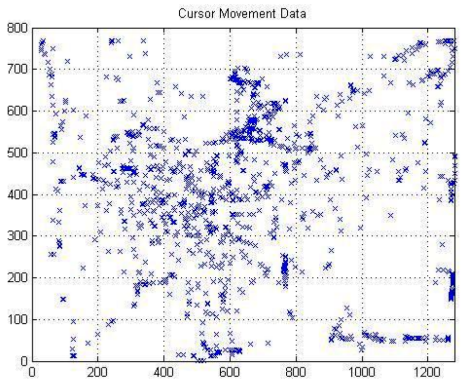


Figure 4.24: Cursor Movements data of a computer user (5 minutes recording)

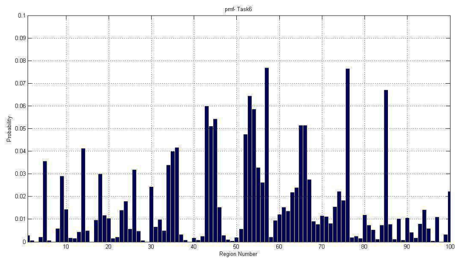


Figure 4.25: Probability Mass Function for data shown in fig 4.24

A simple algorithm was developed for this probabilistic model:

- On- screen gaze projection as in previous sections.
- Got the region number for present cursor position.
- Got the probability of present region (ppresent) from pmf matrix.
- Compared it with probability of the region in which gaze was projected in previous iteration (pprevious)
- If ppresent $\geq$ pprevious
  Project this movement by making the movement equal to 9 x 24.
- else
  Project the gaze after making the movement half of 9 x 24.

Algorithm was applied iteratively on each frame. Lisas eye movements based on Random Walk and on- screen Gaze projections are shown in Figures 4.26 and 4.27 respectively.

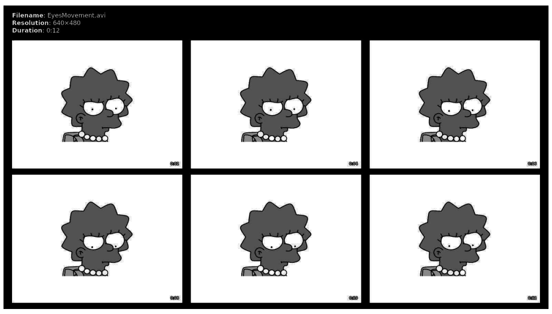


Figure 4.26: Frames from video sequence showing Random walk in Lisa' eyes

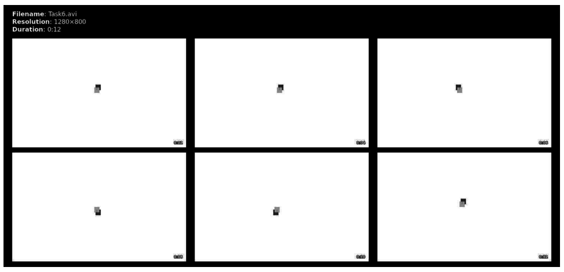


Figure 4.27: Frames from video sequence showing on-screen Gaze Projections (Light Gray: Projections unbiased, Dark Gray: Projections biased towards cursor data)

4.5.5 Filters to be used for Gaze estimation?

Usage of Filters is not new in tracking and estimation applications. Literature review suggested that two of the most common filters could be used in the case of gaze estimation problem i.e. Wiener filter [23] or Particle filter [24].

A detailed study of some useful resources explained the pros and cons of both filters, and specially their areas of applications. Detailed study appreciated the fact that particle filter is best solution to our problem statement. Here is a brief comparison of both filters.

Comparison

Wiener Filter	Particle Filter
If the spectral properties of the signals involved are known, a linear time-invariant filter can be designed whose output would be as close as possible to the original signal [25].	Bayes Filtering is the general term used to discuss the method of using a predict/update cycle to estimate the state of a dynamical system from sensor measurements. There are two types of Bayes Filters: Kalman filters and Particle filters [27].
It is not an adaptive filter because the theory behind this filter assumes that the inputs are stationary [26].	Particle filters are adaptive, as they use a predict/update cycle and updates the statistics in each iteration [27].
Wiener filter assumes spectral properties of inputs and noise are known [25].	Particle filter doesn't require any assumption about spectral properties or probability distribution of data [28].
Wiener filter needs to store all statistical information from beginning (t = 0) to make a good estimation [25].	Particle filters are computationally simple, in form not having to store all data [28].
It is frequently used in the process of deconvolution.	It is being widely used in Computer Vision and tracking applications [25].

Particle Filters and Gaze Estimation

Particle filter is in many ways related to gaze estimation problem, here are some points relating particle filter with the problem statement:

- Particles are differently weighted samples of distribution, like screen regions with different probability (weights).
- Information from recent past is to given more importance; like in current problem present cursor position infers our prediction.
- Predict/update, as gaze pointer system is not stationary, its being varied time to time, user to user, application to application.
- Density distribution may or may not be Gaussian, reasons described in last point also applies here.
- It is being widely used in Computer Vision, tracking applications.

4.5.6 SIR Particle Filter

Particle filter is a very widely used filter; various algorithms have been developed for its implementation [29, 30, 31, 32, 33]. Some of such algorithms are explained in [29]. SIR Particle Filter algorithm proposed in [34] is one of these algorithms. The SIR filter is a Monte Carlo (MC) method that can be applied to recursive Bayesian filtering problems, simple and easy to link up with this application. Here SIR means Sampling, Importance and Resampling.

Algorithm has three steps: Sampling, Importance, and Resampling. Sampling: Initial step in each iteration of mouse pointer, required to locate particles randomly around current cursor position to make prediction. Prediction will be more precise if we increase the number of samples are particles. This was done using a Probability Density Function (pdf) distribution.

$$p(x_k|x^i_{k-1}, z_k)$$

Where x denotes the State of a particle, i.e. the position of the cursor, z is the measurement (observation), and k is the time index. Here we predicted region in which mouse pointer will be in next frame (concept of regions is same as discussed in previous sections 4.6.2 & 4.6.3). Particles were thrown at center point of each region assuming uniform distribution (Sampling weights are shown in Figure 4.28).

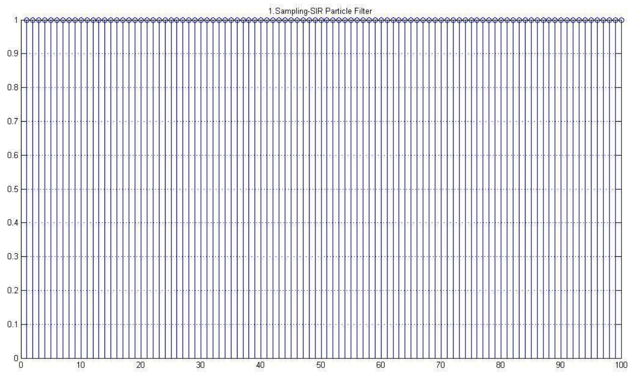


Figure 4.28: Sample Weights at Sampling of SIR Particle Filter

Importance Weighting: In order to make a good prediction, all particles are assigned weights based on the fact how frequently mouse pointer was in a region (Importance weights are shown in Figure 4.29).

$$w_k^i = p(z_k|x_k^i)$$

Then the particle's importance weights are normalized so that sum of all weights equals 1. (Shown in Figure 4.30).For this first total weight of all the particles was found and then divide each particle with the total weight.

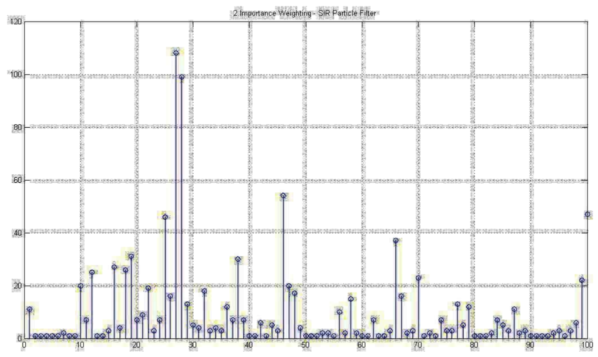


Figure 4.29: Importance Weights at Sampling of SIR Particle Filter

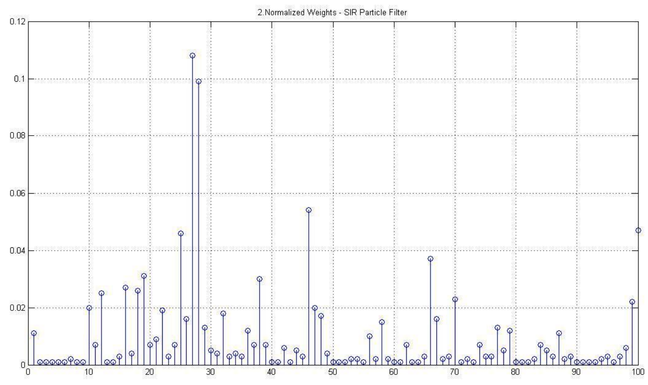


Figure 4.30: Normalized Weights at Sampling of SIR Particle Filter

Resampling: Next step is to re-sample particles so that regions having higher weights have more particles and vice versa. This step is more or less optional in our case, as this doesn't infer the prediction in this task and we're going to predict only region numbers, for which we can only rely on importance weighting.

We used this three step procedure to predict region number (illustrated in Figure 4.31), while movement of cursor was being controlled by random walk method (as described in earlier tasks).

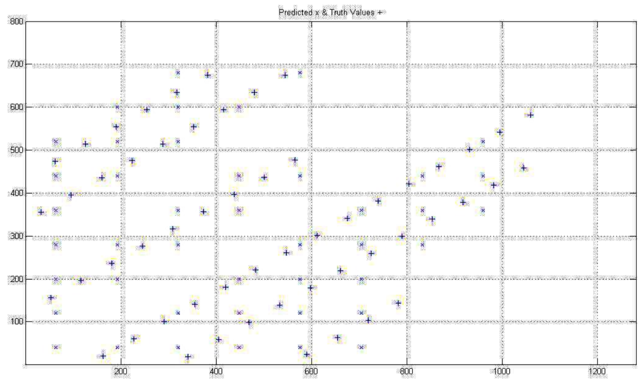


Figure 4.31: Original & Predicted Cursor Positions

Predictions showed were varied, they were satisfactory in central regions of screen, as user statistics recorded for importance weighting showed a biased behaviour towards central regions and were too poor in screen corners.

4.5.7 SIR Particle Filter and Mouse Pointer

Previous task algorithm showed varied results depending on user behavior, and as it was implemented on regions i.e. predicting only regions, it could not be more appropriate to conclude that algorithm may help or not in making a final prediction about Mouse pointer position. Another important thing worth mentioning is that here algorithm is predicting random movements (that is worst case), so if our algorithm achieves an accuracy of more than 50%, then we can trust it to yield satisfactory results for cursor movements initiated by human.

Some enhancements were made in previous section algorithm. Regions were converted into cursor positions in sampling stage i.e. a cursor position (shown in Figure 4.32) and particles were dropped at probable cursor positions assuming uniform density (a zoomed view of dropped particles is shown in Figure 4.33 for Cursor position of Figure 4.32).

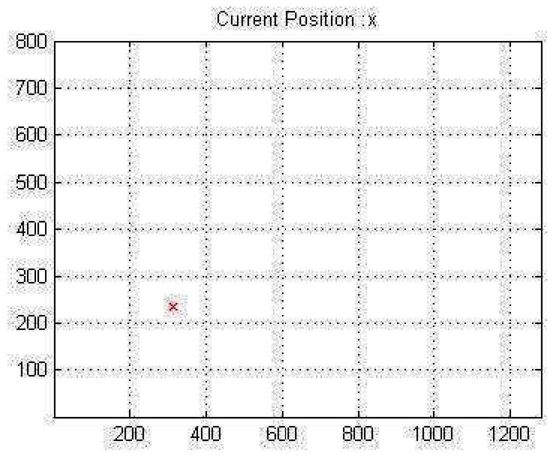


Figure 4.32: Present Mouse cursor position

In importance weighting step, we merged our region importance weighting theory from earlier tasks with a method described in [29]. Than we multiplied the particle importance weight with decreasing exponential i.e. e^{-d}.

$$w_k^i = p(z_k|x_k^i)$$
$$w_k^i x e^{-d}$$

Here w is weight of a particle, x is the cursor position is the measurement (observation), k is the time index and d is the distance between particle position and present Mouse cursor position.

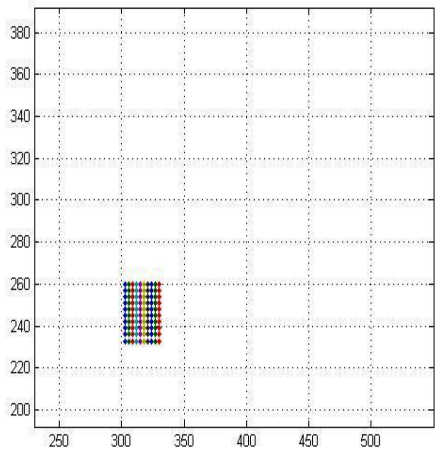


Figure 4.33: Zoomed view of particles for present Mouse cursor position

At final stage prediction was made by finding the maximum of normalized weights and the algorithm outputs this particle position as its prediction (Shown in Figure 4.34). Next Mouse cursor position was once again computed by random walk method (next cursor position is shown in Figure 4.35)

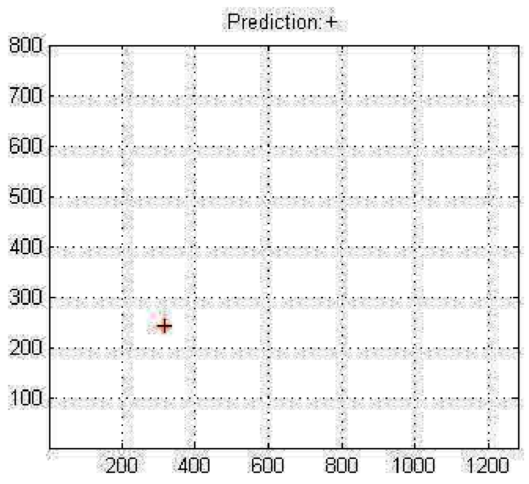


Figure 4.34: Predicted Mouse cursor position

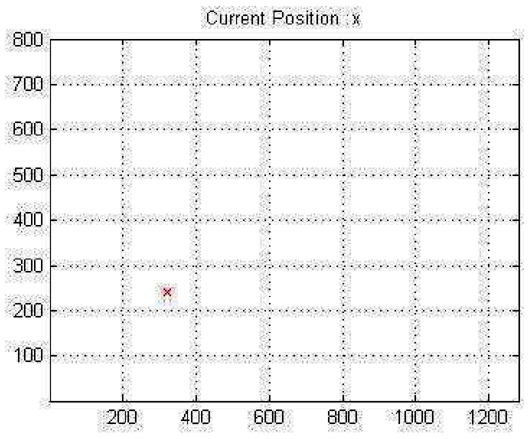


Figure 4.35: Next Mouse cursor position

In this task we did not update our particle weights in each iteration, there is still more work to be done on the particle filters and gaze estimation or prediction.

Chapter 5

Algorithm Implementation Using OpenCV

5.1 OpenCV

OpenCV (Open Source Computer Vision Library) is an open source computer vision and machine learning software library developed by Intel [35]. OpenCV is released under a BSD license and hence its free for both academic and commercial use [36]. OpenCV is often used in real-time vision applications because of its computational efficiency. OpenCV provides implementations in its C, C++, JAVA and Python interfaces and it supports Microsoft Windows, Linux, Android and MAC operating systems. OpenCV has four modules:

cv: These are main OpenCV Functions

cvaux: They are Auxiliary (experimental) OpenCV functions

cxcore :They support Linear Algebra

highgui: They support GUI Functions

Several areas of vision are covered with over 500 functions in OpenCV library, and its goal is to provide a simple-to-use computer vision infrastructure to build fairly sophisticated vision application quickly [37].

OpenCV 2.42 version is used for implementation of algorithms for GazePointer. Both C/C++ are used. But during iris detection C programming language is used with OpenCV libraries, while in eye corners detection both C and C++ programming languages are used.

5.2 Face and Eyes Detection Using OpenCV

5.2.1 Theory

Face and eyes detection algorithms are being deployed in a wide variety of applications. As this project entirely depends on face and eyes detection results. So choosing an appropriate detection algorithm was an important task. Face detection was just the first phase of object detection pipeline where object detection algorithms involved in this project need to locate features, which in this case are eyes and then going more deep siting eyes features like eye corners and center of iris detection. The algorithm should perform accurate detection and should be less time consuming as per this project's requirement. Detector being used here for face and eyes detection is based on Viola and Jones object detection algorithm and uses haar classifier technique.

5.2.2 Finding Face and Eyes

Finding face and eyes means to locate composite objects, in OpenCV a statistical model known as classifier is used, which is trained to locate the required object. The classifiers are trained with the help of 'positive' and 'negative' samples,one of them contain object of interest and other don't contain.

A set of features are obtained when statistical model is educated with images and distinctive features are selected that can help in classifying the object. As a result a detector is received with the quality of finding desired object. The detector used by OpenCV is called Haar Cascade Classifier and uses simple rectangular features, called Haar features [37]. In classifier 'cascade' means that it comprises of many simple classifiers which are applied on the region of interest until it is rejected or passed through all stages.

The feature is specified by its position and shape in the region of concern and also with its scale. And the Haar feature is calculated or found by the difference between dark-region and light-region pixel values.And a threshold value is fixed during its learning i.e. feature will be said to be present if difference value comes out to be greater than the value fixed as threshold.

Integral Image is a technique used by Viola and Jones to check the absence or presence of Haar Features efficiently at different scales and each image location.In this case 'integrating' means to sum pixel values i.e. addition of pixels above and left of a pixel is marked as its integral value. Similarly integration can be applied on whole image with some integral operations on each pixel.

Face detection process is basically about sliding a window named 'search window' above the image to check that if any of the image portion considered as 'face object' or not.A fixed scale is assumed by the detector, but as face size can be different from assumed scale, so a range of sizes is selected across which 'search window' slides through the image several times.

Similar procedure is followed for the eyes detection but this time "search window" goes through the image of detected and cropped face.

OpenCV have a number of classifiers like classifier for profile faces, frontal faces, eyes, nose, mouth,lower body, upper body, etc.

The data from the XML file is utilized by the classifier to determine that how each image location can be classified. XML files also includes three non-face XML files - one for full body (pedestrian) detection, one for upper body, and one for lower body [38].

Classifier need to be told that where it can find the desired data file. The classifiers used was $lbpcascade\_frontalface.xml$ and for eyes it was:

$haarcascade\_mcs\_eyepair\_big.xml$.

So this algorithm will work only for the frontal face images, as in normal scenarios user interact with computer face towards it, detecting frontal images will not be an issue for the whole project's scenario.

5.2.3 Implementation

Implementation of face and eyes detection algorithm was not a big issue remained after because of the functions already available in OpenCV library. Let's have a look upon face detection implementation first.

Face Detection

As processing is to be performed on each frame from live stream from the web-cam, so `VideoCapture` is being used to acquire frames from the web-cam and for further processing.

For locating the XML for frontal face the following code was deployed.

```
String face_cascade_name = ``data/lbpcascades/lbpcascade_frontalface.xml'';
```

The variable $CascadeClassifierface\_cascade$ has the data of the XML file. To load the XML data into variable $face\_cascade$, Load function was used, as

```
        face_cascade.load( face_cascade_name );
```

Most importantly here a mechanism of downscaling was introduced, as a limited time to process a frame was available and if face detection was applied on high resolution image that was more time demanding. Downscaling was applied to reduce pixels density five times from the original image pixels density.

```
        Size dsize(frame.cols/5, frame.rows/5);
```

This classifier algorithm only intakes gray scale images, so the BGR image f_frame was firstly transferred to grayscale and resized. And then histogram is equalized.

```
        cvtColor( f_frame, frame_gray, CV_BGR2GRAY );

        equalizeHist( frame_gray, frame_gray );
```

Now **faces** were to be detected for this purpose the function *detectMultiscale* was used which in return gives the list of rectangles for detected objects. The function was used in the algorithm as:

```
face_cascade.detectMultiScale( frame_gray, faces, 1.2, 3, 0|CV_HAAR_SCALE_IMAGE,
 Size(30, 30) );
```

Now further was quite simple, for extracting the face region algorithm loop through **faces** and draw a rectangle on face location. The next step was to detect and extract eyes region from the face region separated from acquired frame.

Eyes Detection

Eyes detection was performed on the same basis as the face detection. But this time extracted face named *faceROI* was being used as an input image for the eyes detection.
For locating the XML file and then loading its data following functions was used:

```
String eyes_cascade_name = ``data/haarcascades/haarcascade_mcs_eyepair_big.xml'';
        eyes_cascade.load( eyes_cascade_name );
```

Here also downscaling was applied on image of cropped face to reduce pixels density twice of the original density and the reason was same to process the single frame within the limited time constraint.

```
        Size  esize(frame.cols/2, frame.rows/2);
```

The BGR image *faceROI* is converted to grayscale and then optionally resized. Then histogram is equalized.

```
        cvtColor(faceROI, e_gray, CV_BGR2GRAY );

        equalizeHist( e_gray, faceROI);
```

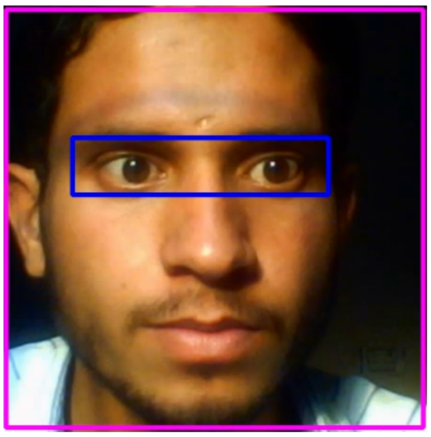


Figure 5.1: Face after cropping and marking eye patch with blue rectangle

The function detectMultiscale is applied and In this case, the vector **eyes** will save the returned data.

```
eyes_cascade.detectMultiScale( faceROI, eyes, 1.2, 3, 0 , Size(0, 0) );
```

Then for extracting the eyes region algorithm loop through **eyes** and draw a rectangle on eyes location and eye patch is cropped(shown in figure 5.2).

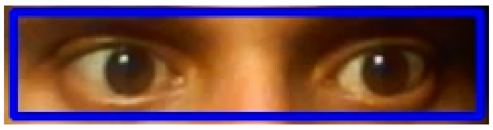


Figure 5.2: Cropped eye patch

5.3 Pupil Detection using OpenCV

Technique of Hough Circular Transform is used for iris detection. Same steps were performed for iris detection in OpenCV as were performed in MATLAB®. First, the input image is enhanced for good quality and then "Hough Circular transform" is applied on it.

5.3.1 Image Enhancement

Eyes frames already extracted in previous step are here qualitatively enhanced for better results.

The image is in MAT form as OpenCV process images in MAT format. The image is first converted into grayscale image. Conversion of image into grayscale is done through '`cvtColor( img, gray, CV_BGR2GRAY )`'. The first two parameters show the source and destination location of the image simultaneously. The last parameter converts the image to grayscale.

After gray scale conversion, image smoothening is applied to reduce noise. For this purpose, the function of

```
GaussianBlur( src img, dest img, Size(7; 7) Gaussian deviation in x direction;
 Gaussian deviation in y direction).
```

This function in takes the source image, the second parameter shows the location of the output image to be saved, next it shows Gaussian kernel parameter, taking its height and width. The last parameters illustrate Gaussian deviation in x and y direction.

5.3.2 Hough Circle Transform

The technique used for iris detection is 'Hough Circular Transform'. Using this function, passes the image through an edge detector .In this case, canny edge detection is used.

The function used is:

```
HoughCircles(gray, gray, CV_HOUGH_GRADIENT, i, 2, gray.cols/3, 30, 30,
 min radius, max radius);
```

The first two parameters show the input and output location of the image.
'*CV_HOUGH_GRADIENT*' tells the method used for detection. In OpenCV this is the method used by default. The third parameter shows the accumulator resolution which is automatically divided by 2, to make it half the size of the image. It basically tells about the targeted points of the circle detection. Where i shows the inverse resolution ratio. '$gray.cols/3$', is the minimum distance required between two distinct circles. The next two parameters 30, 30 are the canny edge threshold. The final two parameters are the minimum and maximum radius of circles to be found in an image.

Vector is formed of the points of the circle. '$vector < Vec3f > circles$'. It is a three dimensional vector as it requires two x and y direction lengths and a center point of the circle. The value of these three points is stored in circles. After this, circle center and outline are drawn around it. Circle center is displayed by

'`circle (img, center, 3, scalar(R, G, B), thickness, line type, setoff);`'.

The first two parameters show the source image and its center. Next parameter shows image colored components. Thickness and line type tells about the type of line and its thickness used for circle drawing. Whereas, 'setoff' is the point how far a circle can be drawn away from the original image. Similarly, circle outline is also shown with the above function only the color contrast are different '$scalar(R, G, B)$' values are set to different from the circle center to be plotted clearly. In the end image is shown in a window by using the command '`namedWindow(circles,1);`'. Circles shows the name of the window and 1 illustrates that window can vary its size according to the image. The results for iris detection using HCT algorithm are shown in Figure (5.3).

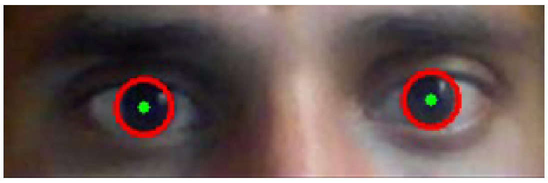


Figure 5.3: HCT Results (Green Points indicating Pupil)

The processing time for this algorithm was 13 - 15 mS, which is much less as compared to the MATLAB® implementation.

5.4 Eye Corner Extraction

5.4.1 Introduction

Corners extraction have always been a point of interest in computer vision. It has been interesting as they are two dimensional features and could be easily detected. In this project eye corners are being detected, as they are an important feature and are necessary to calculate point of gaze. This is performed on the contours of the eye therefore it becomes difficult to find the position of eye corners repeatedly, as they are to be found on the same image.

Eye corners are such an important eye feature that a lot of information about eyes can be extracted using eye corner locations. Once eye corner locations are known to system, it can calculate eye width, can make a guess about eye height and most importantly this information can be used to locate center of eye.

5.4.2 Methodology

The following algorithms available in OpenCV were implemented:

1. Contour finding
2. Good Features to Track
3. Template Matching

Contour Finding

Contour finding is an algorithm to find contour in an image. To apply this algorithm the incoming image must be converted into binary image. Any technique can be applied to convert an image into binary i.e. Thresholding, adaptive Thresholding or using different edge detection based techniques. In this algorithm Canny Edge detector is being used.

Now the contour to be found can be located by scanning the image repeatedly. In contour finding algorithm, firstly, the boundary pixels of the object are detected. The components of the image identified are then analyzed, and edges are detected from it by the minimum and maximum value defined.

OpenCV Implementation

An image was processed. For the conversion of BGR image to gray scale, a method `cvtcolor(srcimage,dest image,CV_BGR2GRAY);` from the OpenCV library was used. The first parameter of cvtcolor, src image shows which image to convert, second parameter defines destination to place the converted image and the last argument use the OpenCV library function CV_BGR2GRAY to convert the image from BGR color space to GRAY.

After the conversion of image to grayscale, the image is blurred with the help of OpenCV library function `blur(src image, dest image, size(3,3) );`. The first parameter takes the source image, 'dest image' tells the destination place o the output image and the last argument tells the size of the object to be made blurr. Canny Edge detector is applied using function `Canny (src gray image, canny output, threshold, threshold*2, kernelsize);`.

The 'source image' displays the image in gray scale. Second parameter is the output of canny detection. threshold provides the lower threshold. 'threshold*2' gives the higher threshold for canny detector.

Good Features to Track

Arrival of floating-point processors in the market have made it possible to perform eigen value decomposition on these processors, and this has minimized the simplifications introduced due to incapability of processors to perform such operations.

A second new concept helps the idea of feature-point clustering. Introduction of local maxima condition has an impact on feature detection, but even then mostly they are unevenly distributed. Solution to this problem is to apply a minimum distance condition between feature points. This solution has been implemented in OpenCV library function '$cv :: goodFeaturesToTrack$'. As the function's name suggests features detected by this function can act as good features for tracking [39].

This function has many parameters for tuning it and extracting the required features. It needs a quality level threshold value to find features and then these extracted features can be minimized by threshold for minimum tolerated distance between feature points and then further these features can be reduced by another parameter which tells the function maximum number of feature points to be extracted. These parameters can be tuned to acquire desired corner/feature points.

This approach exploits the tuning of parameters to acquire desired results and make this approach very complex, as this implementation requires each features point to be stored and sorted by their Harris score. Of course, this approach will result in higher processing time but outputs can be improved by tuning the parameters, a tradeoff exists between performance and processing time.

OpenCV Implementation for cv::goodFeaturestoTrack

```
cv::goodFeaturesToTrack(image,corners, maxNumberOfCorners, qualityLevel,
 minAllowedDistance);
```

image: input image, in which features/corners are to be detected.

corners: vector in which detected features/corners are to be stored.

maxNumberOfCorners: Maximum Number of Corners to be returned.

qualityLevel : Quality level threshold for features/corners detection.

maxAllowedDistance: Minimum allowed Distance between detected feature points.

Unfortunately, this approach could not provide satisfactory results for eye corners detection. It detects correct eye corners points plus many points which are not actually eye corners. So it was concluded that this approach can't be used for eye corners detection.

Template Matching

Template matching is an algorithm to match a template to an image, where template is a portion of the image which is to be located. The template is slide along the input image and pixels values are compared, where the template is matched to a portion of an input image it counts up. This process is repeated for the entire image. The output is generated for the best match (showing where there is maximum match).

In edge detection noise effects a lot due to differentiation, template matching provides us a good solution for it. This technique was helpful due to its noise immunity.

Algorithm

An image is loaded, it is converted from RGB to GRAY scale. From the gray scale image templates are extracted. At this stage frames are initially pre-processed, algorithm attempts to normalize lighting conditions in entire frame.

Then it applies 'Template matching' to find eye corners; templates are collected at calibration stage. The following pre-processing techniques are applied on the input frames (Both on templates and input frames).

Histogram Equalization

The histogram equalization is applied. It is a method to adjust image intensities to improve its contrast. This improves the quality of an image for future implementations. The following function from the OpenCV library is used; `cvEqualizeHist (source,destination)`. The first parameter represents the input image, upon which histogram equalization is applied. The second parameter is the output after applying this method.

Smoothing

Smoothing is applied for the purpose to reduce noise effect. Intensity of a pixel is its 'original intensity' with addition of noise. Therefore, to reduce noise effect in the resultant signals smoothing is applied.

In OpenCV library

```
cvSmooth (source, destination,CV\_Gaussian, int para1, int para2, para3, para4);
```

function is used to implement the smoothing method. 'Source' parameter defines the source image;'destination' tells the output smooth image. 'CV_Gaussian' illustrate the method to be used for smoothing. 'Para1 and Para2 ' are aperture width and height respectively. 'Para3 and Para4' represent Gaussian standard deviation, in case of CV_Gaussian method values of these standard deviation are equal to zero.

Adaptive Thresholding

It is a technique in which threshold level is varied itself. The adaptive threshold technique is required when there are strong illuminated pixels that are needed to threshold relative to the general intensity pixels.

```
cvAdaptiveThreshold(source image, destination image, MaxValue,
 CvAdaptiveThresh_Mean_C, CvThreshBinary,blockSize,  para1);
```

The first two parameters define the source image and the output is shown at destination image respectively. 'MaxValue' illustrates the maximum value with CvThreshBinary and CvThreshBinary_Inv. 'CvAdaptiveThresh_Mean_C' shows which adaptive method to be used, whether, CvAdaptiveThresh_Mean_C or CvAdaptiveThresh_Gaussian_C. 'CvThreshBinary' shows the type of method forthresholding.'blockSize'The size of a pixel neighborhood that is used to calculate a threshold value for the pixel.'para1' Its value depends upon the method used. For CvAdaptiveThresh_Mean_C or CvAdaptiveThresh_Gaussian_C, a constant is subtracted from their mean.

All the above mentioned pre-processing techniques are applied on both templates and the original input image.Now, Template Matching is performed by using a function from OpenCV library

```
matchTemplate( img, temp, result, method );
```

'img' defines the input image. 'temp' tells the template to be matched. 'result' illustrates the best template matched, 'method' describes the method used for template matching.

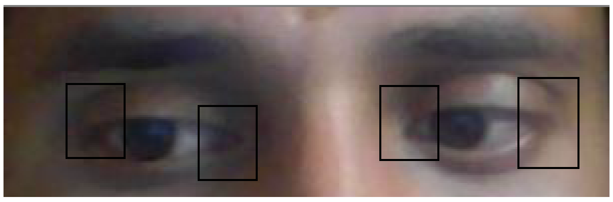


Figure 5.4: Eye Corners marked with rectangles (centres of these denote eye corner points)

5.4.3 Conclusion

All of the above mentioned algorithms were applied for eye corner detection, but only "Template Matching" technique available in OpenCV library to detect eye corners, yielded satisfactory results. This algorithm resulted in satisfactory performance at a fast processing speed. Processing time for each frame using this algorithm was 10–15 mS.

5.5 Point of Gaze Calculation

5.5.1 Point of Gaze

Point of gaze can be referred as the point of interest of the user in test area he/she looking at or gazing at. Gaze point can be calculated after acquiring the eye location, its features and its movement data. The speed of communication among the user and computer can be enhanced by using the information about what the user is looking at like any application running on computer, and even designing objects especially intended for the user to look at. So there is requirement of finding eyes feature and also getting description about the test screen. To help in point of gaze calculation some of eyes feature were selected i.e. eyes corners, iris and then center of iris detection. In this chapter using these eyes features found previously and information about the test screen like its height and width, different factors necessary for point of gaze calculation were found like reference point and scaling factor computation as discussed below.

5.5.2 Finding the Reference point

As eyes corners detection had been performed (discussed in previous chapter). That corner location was utilized in this step to locate the centers of both eyes, acting as the reference points for gaze calculation. In corner detection procedure eyes corners were marked with rectangles as shown in figure (5.4). As center of eye is the point mid of both corners of an eye. To locate this point simple calculation was applied like siting the center of rectangle drawn for corner detection, which will be the exact point of the corner of eye. As corner of eye is a two dimensional point so to locate eye corner point some pixels addition or subtraction will be required along x-axis and y-axis from the edge of the rectangle. Centers of both left and right eyes were found using the given equation.

$$Centerofeye(x,y) = \frac{(RightCOE+15+10)+(LeftCOE+15-10)}{2}, \frac{(RightCOE+15+10)+(LeftCOE+15-10)}{2}$$

Here 'RightCOE' and 'LeftCOE' represent right and left corner of eye respectively. '15' is the number of pixels added along horizontal direction from the corner of rectangle to get the x-coordinate value of the eye corner and '22' is added to determine y–coordinate value. Whereas the number '10' is added in the x–coordinate of the right eye corner point and subtracted from the left eye corner to estimate the moveable area available to pupil inside eye region because pupil can't move to the extreme ends of the eye along horizontal direction. And then for finding the center of eye mid–point of both left and right corners is found as shown in above equation. This calculation of reference point is similar for both left and right eyes.

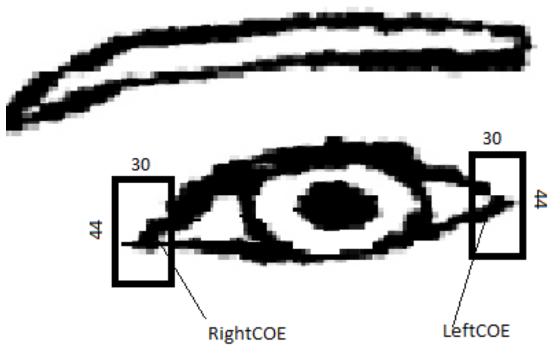


Figure 5.5: dimensions of rectangles used for corner detection

5.5.3 Calculating the Scaling factor

In this step the cursor movements and pupil movements were interrelated i.e. it was to be found that how many pixels a cursor will traverse for a single movement of the pupil. For this calculation width and height of eyes were associated with the width and height of the screen. Now to calculate width of the eye following equation was used.

$$EyeWidth = (LeftCOE - 10) - (RightCOE + 10)$$

As height of an eye varies from 28% to 32% of the width of eye. Here height is calculated by considering it to be 28% of the width.

$$EyeHeight = EyeWidth \times \frac{28}{100}$$

This calculation of width and height is same for both left and right eyes. As width and height of both eyes might vary because of some false detections in one or both eyes. To reduce the error due to this detection width and height averages were found i.e. 'AvgWidth' and 'AvgHeight' respectively. Scaling factor was calculated by dividing the width and height of test area with average width and average height of eyes respectively.

$$RxFactor = \frac{TestWidth}{AvgWidth}$$

$$RyFactor = \frac{TestHeight}{AvgHeight}$$

5.5.4 Computing the Point of Gaze

Point of gaze was calculated using all the results and steps performed earlier. Here the focus was on pupil movement and displacement from the reference point or center of the each eye separately. The translation of center of iris from the center of eye was calculated separately for left and right eyes.

$$RightR(x, y) = rightCOEye(x, y)RightCOI(x, y)$$

$$LeftR(x, y) = leftCOEye(x, y)LeftCOI(x, y)$$

In above equations ‘rightCOEye(x,y)’ and ‘leftCOEye (x,y)’ are the centers of left and right eyes respectively . Similarly ‘RightCOI(x,y)’ is the right eye’s center of iris point and ‘LeftCOI (x,y)’ is the left eye’s center of iris.

Now again the relative distance of center of iris and center of eye were averaged to reduce the error if any in the iris detection or also it can be said as for a better estimation of gaze pointing including both eyes relative distances along both x–axis and y–axis direction.

$$RxAvg = \frac{(RightRx + LeftRx)}{2}$$

$$RyAvg = \frac{(RightRx + LeftRx)}{2}$$

Now projection on screen can be found by finding the relative distance from the center of test area associated with the relative motion of center of iris with the center of eye. Following equations were employed to calculate the screen coordinates.

$$Projection(x) = \frac{TestWidth}{2} + RxFactor \times RxAvg$$

$$Projection(y) = \frac{TestHeight}{2} + RyFactor \times RyAvg$$

Where ‘Projection(x)’ and ‘Projection(y)’ are coordinates of the test area for x-axis and y-axis respectively the projection point will be as ‘Projection (x, y)’. This whole procedure for point of gaze calculation is repeated for each frame from the camera.

5.5.5 Limiting and Smoothing the Cursor Motion

As we are trying to implement the cursor movements as the mouse pointer motion on the screen to make these alike smoothing in the mouse pointer movements and introducing limitations to the test screen coordinates.

As in this algorithm one pixel movement in eye results in several pixels traversing on screen coordinates so this results in jerky motion of the cursor. To make the movement smooth enough so that it may look like the original motion of the mouse pointer, values were inserted among the previous and the next value of the cursor position pixel by pixel. This was done by applying “for loop” from previous value of projection to the next value or point calculated.

Now limiting the cursor movements within screen coordinates meant to bind the cursor inside the screen. As if the eyes of the user are looking out of the screen of computer computation may be as the cursor to be out of the region of screen, to limit this some restrictions are applied using if conditions so that if the calculations depict cursor as out of the screen this algorithm will keep and show the cursor to be at the extreme ends of screen.

5.6 Point of Gaze Calculation Algorithm [Live Stream]

Algorithm for pre-recorded sequences worked well for pre-recorded videos, but when tested on live stream of frames captured by web-cam, its performance was not satisfactory. It given rise to need for improvements or rather design a new algorithm for live stream.

For this purpose, experimentation was performed to analyze the difference between both scenarios.

Algorithm results were analyzed for both scenarios and some important observations were made which laid down the basis to modify the algorithm, make it possible to work for live stream. Some important observations are listed below:

- There were a lot of false detections in case of live stream due to environmental characteristics changing all the time i.e. lighting variations.
- Algorithm was same for all situations, but user distance varied every time he/she used application.
- Most important one, Eye corners dont give true information about the movable area for Iris, in user eyes, to see in Test Area of GazePointer GUI.

Now, based on these observations, some modifications in the setup were proposed. For lighting variations, an external lighting source was made available with system, which can be switched on manually when needed, e.g. when lighting conditions are not good or there is no lighting source to illuminate user face, external lighting source should be switched ON.

To rectify the issues because of webcam to user eyes distance variations, a resizing concept was introduced in algorithm. After Eye Patch extraction, it will be resized to a fixed size every time, attempts to fix issues due to distance variations.

Face and Eye Patch was being extracted in every frame, this process resulted in two issues: more processing time per frame and extracted eye patches were not stabilized to that extent they should be, resulting in addition of noise in true values of PoG. To fix these problems, an idea was proposed to detect face and eye patch after every nth frame, and use co-ordinates acquired by last detected face and eyes in intermediate frames. Experimentation was performed and analyzing those experimental results suggested to use value of ‘n=4’.

Another fact is established through last point listed among the observations, eye corners extraction is not suitable to get know about movable area for iris in eye to trace the Test Area in GUI. For this purpose, after analysis it was concluded that computer is not that intelligent to discover those boundary points in eye, user should feed some information to this application at start and some procedures must be implemented to use this information in intelligent way to extract features i.e. movable area for iris, center of eye etc.

A simple 4-point calibration technique was designed to address this problem. User will have to follow the below given procedure at start of application to calibrate system and feed information to be used in calculating PoG:

- Gaze at Top Left Corner of Test Area in GazePointer GUI, and press mouse left button.
- Keep on Gazing for a moment and press mouse left button again.
- Now, Gaze at Top Right Corner of Test Area in GazePointer GUI, and press mouse left button.
- Keep on Gazing for a moment and press mouse left button again.
- Repeat the above process for Bottom Right Corner and then for Bottom Left Corner of Test Area in GazePointer GUI.

This simple calibration procedure will help the user to feed information, system will use this information to extract features and calculate Point of Gaze. Rest of procedures for calculating Point of Gaze will remain same as in case of prerecorded videos.

5.7 Algorithm for Test Bench

Quantifying the accuracy of an algorithm or system is always necessary to justify its usability in real world applications. Test bench models help to quantify accuracy of a system/algorithm in a simulated or ideal environment. In this project accuracy can be measured in two ways: manually by a user or Test Bench. Manual testing will require a lot of labor work and even after wasting plenty of time and money, results will not be as much accurate due to limitations of human eyes, as a human cannot identify and quantify errors in pixels.

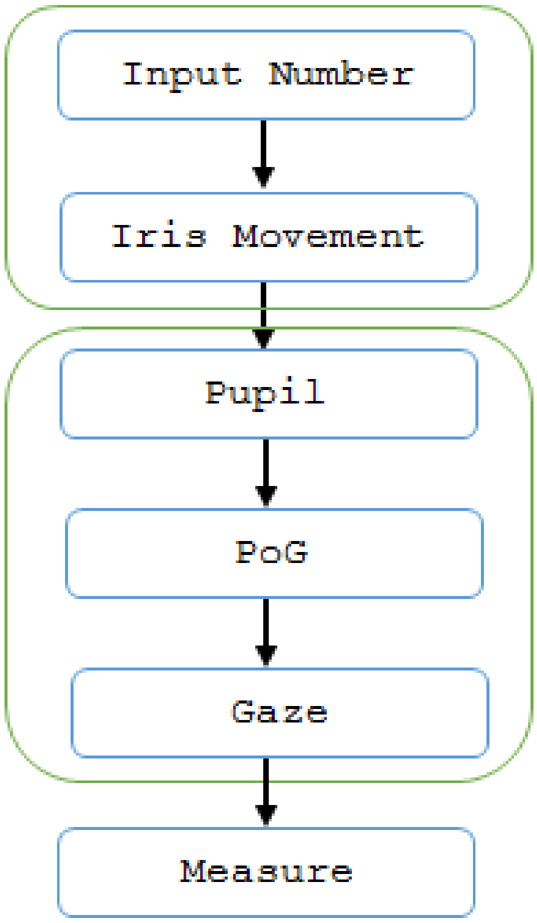


Figure 5.6: Algorithm Overview for Test Bench

Designing simply a Test Bench is an easy and accurate way to measure accuracy of this application. A simple and easy to use Test Bench model was designed to test accuracy of this system. Artificial eyes instead of human eyes are used in this system, and iris moves according to input number entered by user. Application prompts user to input a number by keyboard. User enters a number and iris moves in accordance with input number, algorithm processes these iris movements and projects eye gaze in Test Area. Now user can check whether gaze was projected into area in accordance with input number or not, it will tell him/her about accuracy of application.

Chapter 6

Developing Graphical User Interface Using Qt framework

As soon as results are ready to display, a 'Graphical User Interface' needs to be developed to show results. OpenCV library doesn't provide enough support to develop a customizable GUI with a number of areas. A number of tools were searched to develop a GUI using C/C++, finally, Qt framework was selected. It provides excellent functions for GUI development and extensive documentation makes it easier to develop a GUI using Qt.

Qt is a cross-platform application framework that is widely used for developing application software with a graphical user interface (GUI) , and also used for developing non-GUI programs such as command-line tools and consoles for servers [40].

It consists of two elements: a cross-platform IDE, called Qt Creator, and a set of Qt class libraries and development tools. Qt framework has many advantages including formation of GUI using a cross-platform GUI library, which follows an object-oriented model.

6.1 Introduction to Qt Classes

Qt provides extensive support for GUI development, it offers a lot of different types of classes which can be used to create a user friendly and easily accessible GUI. These Qt classes offer customization to developers, so they can design good looking GUIs. This section is devoted to explain different Qt classes which are being used in GUI development. Each class is being explained under a different heading and it will also explain the usage details of particular class in GUI.

6.1.1 Main Window

A main window is made by creating an instance of QMainWindow(). Different types of widgets can be added to layouts as per requirements and then these layouts can be added to a main layout, which can be added to Main Window. In current GUI implementation an instance of QMainWindow() is created as 'GazePointer'.

6.1.2 Qwidget

Widgets are the main elements for creating UI. The main purpose for using widgets in this project is to display results and to handle user input during calibration stage. Qwidget class is used to create a widget.

Three widgets are created to show results of different stages of algorithm:

1. First Widget shows extracted eye patch after face and eyes detection

2. Second widget is used to display eye patch after processing and it shows detected eye features.

3. A test area showing the mouse pointer movements.

6.1.3 Layouts

Layouts are used to arrange the widgets according to their size and orientation. The size of the widget is provided through the use of 'sizeHint()' property. Layouts in GUI are represented in three main formats: horizontal, vertical and grid layout.

'QHBoxLayout' is used to align the widgets in a horizontal layout. The number and box in the GUI are arranged horizontally in GUI using 'QHBoxLayout' .

'QVBoxLayout' aligns the widgets in a vertical layout. Two widgets are created in vertical orientation to show the original video frames and other to detected iris and eye corners.

'QGridLayout' has aligned all the widgets in the main window in horizontal and vertical alignments as required.

6.1.4 Spacings

Spacings between all the widgets are adjusted by 'setSpacing()'. Spacing are adjusted according to the requirements

6.1.5 CVImageWidget

OpenCV deals with images in Mat, IplImage or CvMat format, unfortunately Qt is unable display frames in these formats. It only handles images in two formats QImage and QPixmap. OpenCV images must be converted to any of the format that Qt support, to display them in GUI. QWidget class can display OpenCV images, if somehow OpenCV image can be converted to QImage format. QImage class has support for in-memory construction, that is, a QImage can be assigned to an existing image stored in the memory [41].

OpenCV stores color images in BGR format but Qt handles color images in RGB format, therefore, OpenCV image is first converted to RGB image before converting to QImage. An image widget class is created to display the image. Firstly a QImage is stored in memory and then point the converted (RGB) OpenCV image to Qimage. The widget itself updates the image in memory. Qt can display QImage using QPainter::DrawImage. Three image widgets are created and assigned to vertical layouts. In the first widget the frames are being showed after extracting eye patch, the next widget shows eye patch after processing, and another widget to show test area for mouse pointer movement.

6.1.6 QSlider

A slider is created to control the speed of mouse pointer using the command QSlider. It is adjusted in a vertical layout using QVBoxLayout. It converts the rate of change in mouse position according to the slider position and converts the position to an integer value to perform the required function. Position of the slider is fixed by giving it maximum and minimum values using setFixedSize(max val, min val).

6.1.7 QLabel

Below the image widget a QLabel command is used to give the title or name. The QLabel is used for the slider. The name is given to the slider using QLabel, 'Speed Slider'. In the end a label is formed with name 'Number'. Along , with it a QLineEdit widget is used. Using this a user can edit or enter text in the line.

Moreover, QFont, setPixelSize(pixel value) and setAlignment(widgetname,Qt::AlignFormat) are used to set the font type,size and alignment (centre, left, right) of the title simultaneously.

6.1.8 QPushButton

QPushButtons are command to perform a certain function. In this GUI two push buttons are created i.e, a button is created to show the 'GazePad Mode' and another to show 'GazePointer Mode'. Both the buttons are created using command QPushButton. By using function of setFixedSize(length, width) both the fixed size buttons.

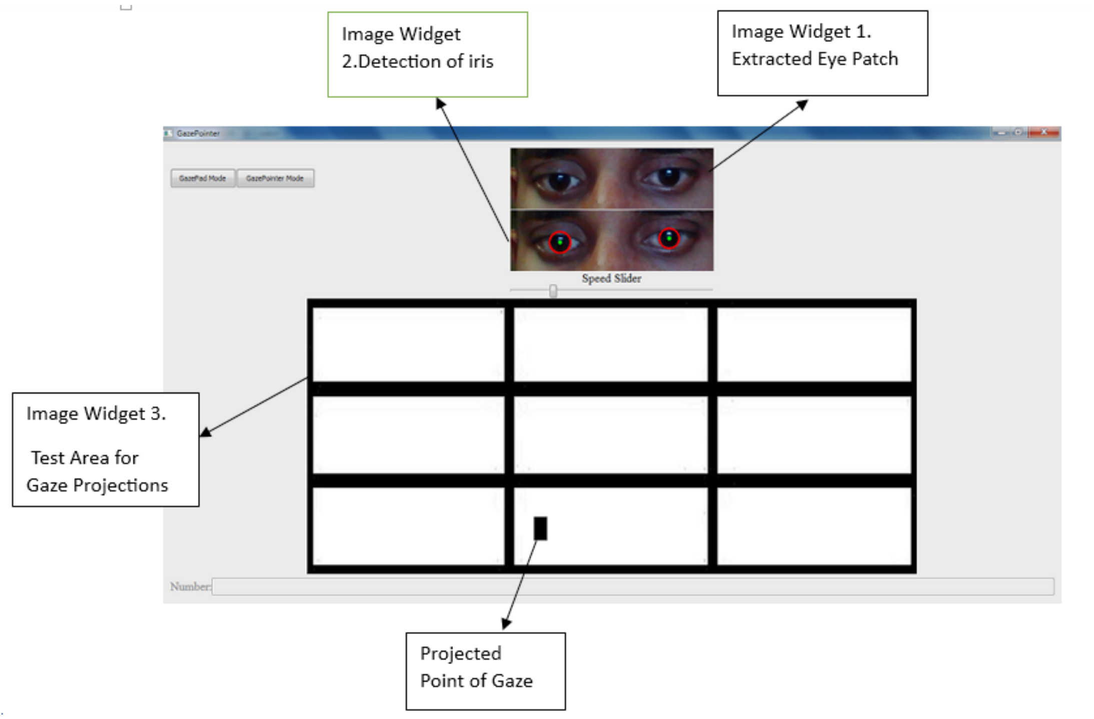


Figure 6.1: GUI Image

6.2 Calibration

Calibration techniques always aid to improve system performance, they help the systems to adjust parameters in order to behave in a way that is more user friendly. Certain calibration techniques are being applied in this project at start of program. Using a greater number of calibration points helps to achieve better gaze projection results.

The algorithm starts with face and eyes detection, it then resizes the extracted patch to a fixed size in order to introduce the concept of scalability. It will adjust the issues because of distance variations between user's eyes and webcam. This extracted, resized eye patch is being shown in first widget of GUI. It will not go for further processing i.e. pupil detection, until user feels him/herself comfortable and wants to start calibration. The user can tell the system to stop capturing images and proceed to calibration stage by clicking on GUI.

When a user click once the GUI, image becomes static. Now, the user marks its four eye corners i.e., right eye right corner, right eye left corner, left eye right corner, left eye left corner. After feeding the system with eye corner points, user proceed further with calibration and marks right and left pupil. Again, user left clicks on the GUI and the program starts capturing frames and then it applies all of the processes explained in previous chapters, on each frame.

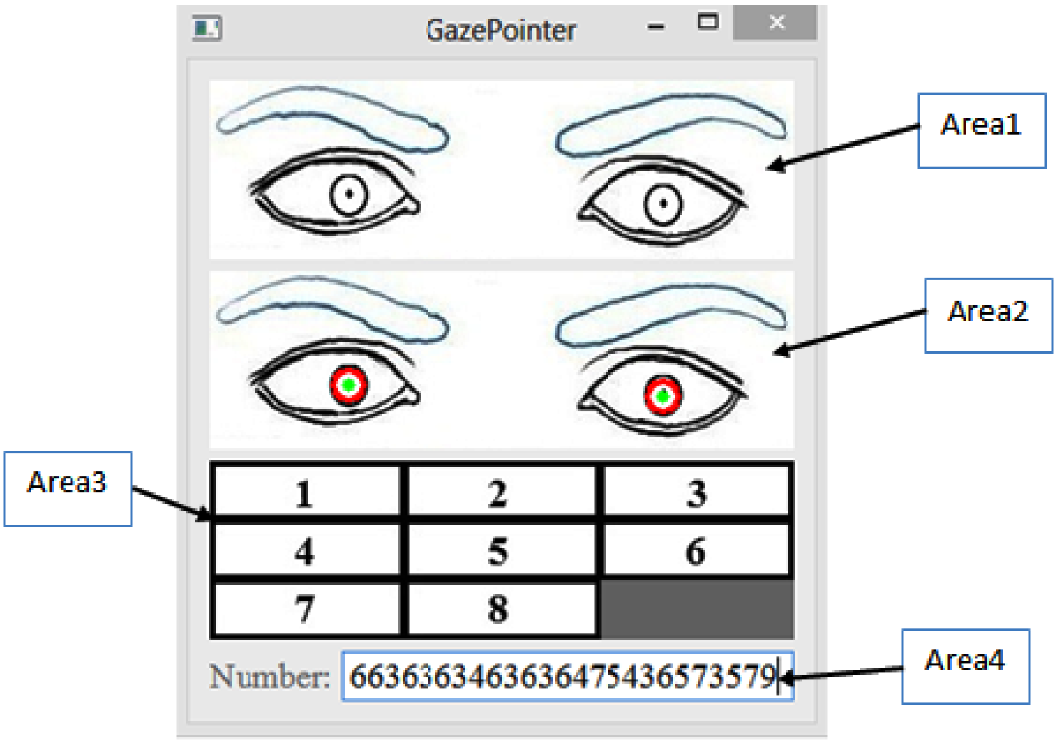
During the calibrations stage, when user feed the eye corner points, system also collects templates for eye corners. System requires these templates for eye corners extraction stage, where it is using template matching algorithm for eye corners detection. Template Matching is already explained in section 5.3.

The more robust the process of calibration the better the results are achieved. This calibration process is simple, as user can take as much time to adapt to the environment, when the user feels comfortable, he/she can then mark the eye corners on stationary image of the eyes.

6.3 Test Bench GUI

Algorithm for Test Bench model is explained in chapter 5, this section attempts to describe the different areas of Test Bench GUI. Test Bench GUI is shown in Figure 6.2, it is following the flow of GazePointer GUI except a Text Box below the Test Area, which is intended to show results in number format. It has four areas:

- Area1: showing artificial eyes
- Area2: Showing processing results
- Area3: Test Area (for Gaze Projection)
- Area4: Text Box to show Region Number.



Number: 66363634636364754365735 79

Figure 6.2: Test Bench GUI

When User run this GUI application, a command prompt screen will appear, user will enter a number in between 1-9. Iris in artificial eyes will move in accordance with input number and shown in Area1. Processing results will be shown in Area2. Gaze will be projected in Test Area, a number will be entered into the Text Box (below to Test Area in GUI) according to gaze projection.

Chapter 7

Result and Discussion

This chapter is devoted to evaluate results of GazePointer implementation using OpenCV. It will follow the flow of algorithm, starting with face detection then evaluating eye patch extraction, later it will discuss results of pupil detection and then eye corners extraction.

7.1 Face Detection

OpenCV library provides a high performance implementation of face detection in different environments. As it is explained earlier, it is not a skin color based approach so detection rate does not deteriorate with different background colors or with different lighting environments. Face detection implementation provides satisfactory results in outdoor as well as indoor environments. Accuracy does not drops with changing lighting conditions, backgrounds, and distance while using a computer. Face needs to be frontal, it will not detect profile faces, a limited level mobility is available for face. It also detects face accurately even when user is wearing glasses.

According to limitations of this system explained in chapter 3, Face detection accuracy remained 100% when tested on a limited dataset of 223 frames. Generally face detection results were quite satisfactory in every environment, and this is as it should be, because it is a preliminary stage and accuracy of this stage must remain above 95% ideally.

As explained earlier in chapter 5, that face detection is a complex process and it requires a lot of complex processes to be done in a series to detect a face accurately, so detection time will always be high especially for high resolution images. GazePointer is assumed to be a system working with real-time constraints, so to reduce the computation time captured frames are downsampled 5 times (both sides, in width and height). Before resizing the frame, face detection took 500–600 mS per frame and it reduced to only 13–15 mS per frame.

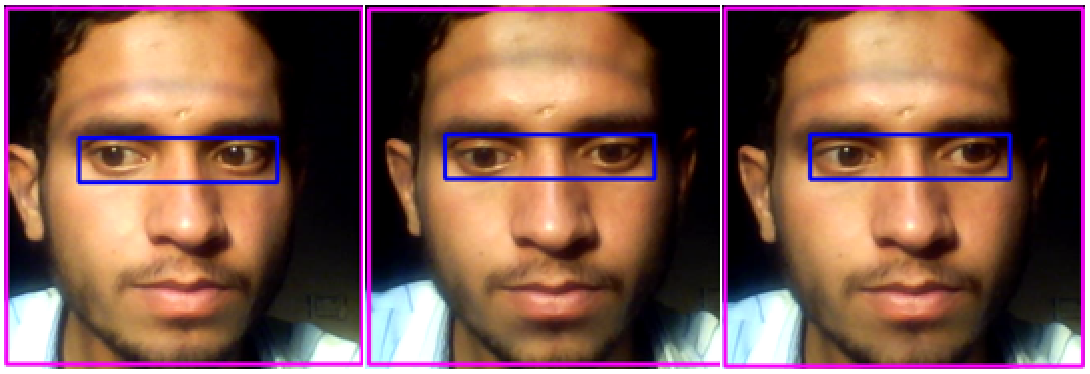


Figure 7.1: Face and Eyes Detection Results in Different Frame

7.2 Eyes Detection

Objection Detection module in OpenCV also provides implementation for eyes detection. Eye patch extraction is being done accurately in almost every case when face is detected. This module was also tested on a limited dataset of 223 frames and it resulted in 100% accuracy. Generally in any environment according to system limitations defined in chapter 3, eyes detection accuracy does not drops to 90%.

Eyes detection implementation provided in OpenCV library results in a large computation time. To reduce computation time, first of all region of interest was limited to detected face only, then face region was downsampled 2 times (both sides, in width and height). Computation time was reduced to 10–15 mS per frame after modifying the implementation.

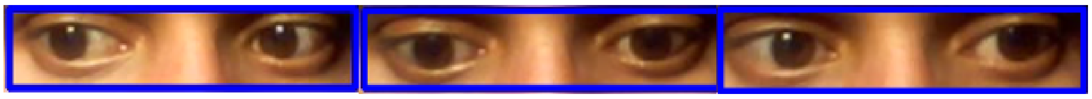


Figure 7.2: Cropped Eye Patch in different frames

7.3 Pupil Detection

HCT implementation was quite light weight and resulted in a few mS processing time per second, but initial algorithm resulted in a lot of false detections. It took 6–10 mS per frame for processing and an accuracy of 80% when tested on a limited dataset of 223 frames.

These false detections and less computation time implied that some other processing should be performed to improve accuracy. While analyzing the results, it was concluding that applying a threshold between previous frame pupil location and present frame pupil location, accuracy can be enhanced. After applying the threshold, the accuracy improved to 87% with a slight increase of 0.5–1mS processing time per frame.

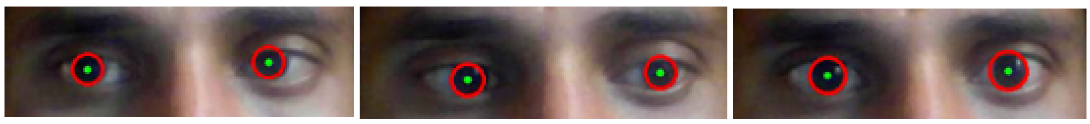


Figure 7.3: Pupil detection in different frames

7.4 Eye Corners Extraction

Template matching provided good results for eye corners extraction. After testing the algorithm in different environments, it was concluded that template matching performance deteriorates with lighting variation. Lighting conditions while collecting templates and while testing should be same. This technique is quite demanding in terms of lighting, lighting conditions should be quite good to achieve a satisfactory detection rate. It provides excellent results when facing the sun, as no light is available at back to produce shadows and sun is enlightening the face. This observation is quite helpful in quantifying the quality of results, and we can conclude that eye corners will be extracted accurately when lighting conditions are quite good and remain same throughout during the calibration and using the application.

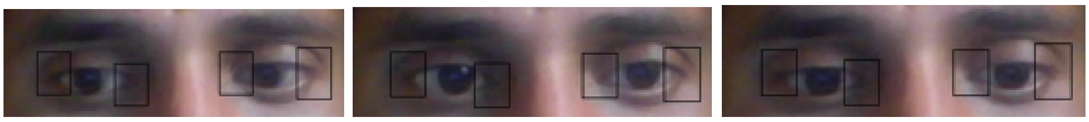


Figure 7.4: Eye Corners Extraction in different frames

Template Matching resulted in 80.7% accuracy when tested on a limited dataset of 223 frames (recorded in good lighting environment). As in the case of Pupil detection, after applying a threshold accuracy for eye corners detection was improved to 94.1%.

7.5 Point of Gaze Calculation [Live Stream]

Detection results for eye features required to calculate Point of Gaze were good, while testing on a limited dataset. This section presents a qualitative analysis of point of calculation algorithm tested on live stream of frames coming from webcam.

Most of the times pointer follows the user eye-gaze in Test Area, but sometimes there are false projections, as image processing algorithm employed for detections i.e. HCT for Pupil detection are not 100% accurate. Pointer size is quite large, because low resolution webcam already available in laptop is being used as a capturing device. A few results are shown in Figure 7.5.

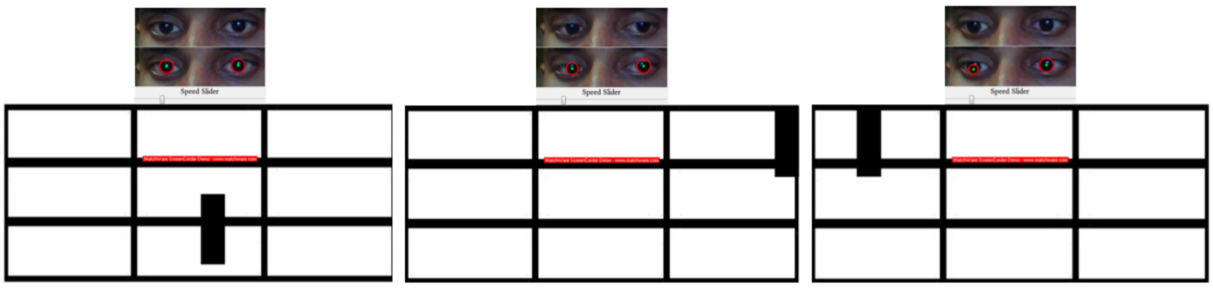
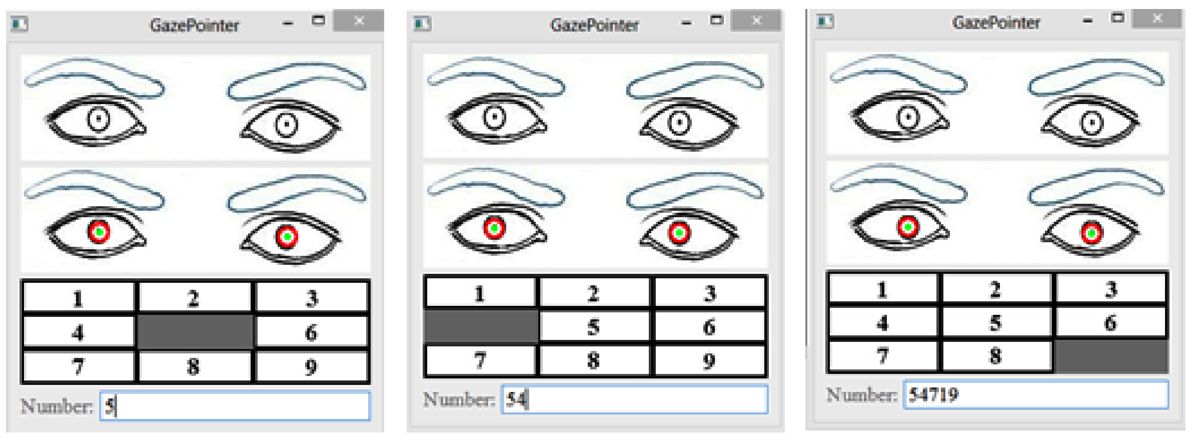


Figure 7.5: Some Results of Test Bench Model

A threshold was applied on distance between previous and present Point of Gaze, which helped to identify false projections due to erroneous projections. This threshold was decided very carefully after experimentation.

7.6 Test Bench

Test Bench model was tested in idea environment, just to verify the correctness of algorithms. Idea was to draw conclusions from this research and justify reasons given for false projections. This Test Bench model was tested many times and its accuracy remained 100%. Pupil detection accuracy remained 100% throughout the experimentation and gaze projection algorithm also resulted in 100% accuracy. A few results are shown in Figure 7.6.



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Number: 54

Number: 54719

Figure 7.6: Some Results of Test Bench Model

This accuracy of 100% shows the correctness of algorithms employed, also justifies the reasons explained for false projections and detections. Test Bench results established the fact that work done under this project is substantial and algorithm for eye gaze projection is reliable.

Chapter 8

Conclusion & Future Work

This chapter details main conclusions of this project, discusses possible enhancements and gives proposals for future research in this field.

8.1 Conclusion

In this thesis, a Human Computer Interaction application is developed using concept of Eye Gaze Tracking. The main objective of testing the potential of eye gaze as a possible means of interaction and to develop an eye-gaze based interaction application using built-in camera available in computing devices is accomplished.

Eye gaze tracking is a complex problem and there can be many solutions to address this problem. In this project a computer vision algorithms based solution is implemented. A low cost, real-time solution for eye gaze tracking is developed with help of OpenCV library. There are many applications of eye gaze tracking, for instance in HCI, appliances control, usability studies and in advertising effectiveness.

Accuracy for facial features extraction algorithms depend on image quality and lighting conditions. Algorithm performance drops down in poor lighting environment i.e. light coming from back side of user causing shadow, low light intensity on face. Algorithm accuracy deteriorate in lighting variant environments. Computer Vision algorithms are employed for features detection and they dont perform well in lighting environments discussed earlier.

Point of gaze (PoG) calculation is a crucial stage in this project, multiple features are combined in a systematic way to result in accurate calculation of PoG. Simple mathematical equations relate these feature points to PoG. PoG is accurately calculated provided detections are correct, only a few erroneous PoG projections were found and reason was false detections in features detection stage. Pointer size is large due to low resolution and small Test Area.

Test Bench model is developed to test algorithm in ideal environment and to infer conclusions about false projections. This model verified the correctness of algorithm and accuracy proved to be 100%. This also confirms the reason for erroneous projections to be, performance of computer vision algorithms in lighting variant environment and poor lighting conditions.

8.2 Future Work

To improve the projection results, image quality must be enhanced. Better image quality would improve accuracy of computer vision algorithms. Sophisticated pre-processing algorithms should be introduced to compensate lighting variations and webcam resolution should also be increased to decrease pointer size.

Computer vision algorithms employed for features detection must also be refined, it will enhance detection accuracy and in-effect projection results. A feature describing head-posture must also be introduced, it will allow the user to move-freely while interacting with system.

Introducing the concept of gaze estimation along with gaze projection will be beneficial because it will improve gaze projections drastically. This idea is of more importance because it will cause a tremendous improvement in user experience, as the idea of gaze estimation promises to learn from usage statistics and infer gaze projections. Gaze estimation is discussed in Chapter 4 of this thesis, work done under this project on gaze estimation was not substantial, readers are suggested to refer the incomplete work and carry out research work on Gaze Estimation. Particle Filters should be preferred to implement gaze estimation because they are quite simple and has resemblance with problem of gaze estimation.

It is a real-time application, there is no more work to be done in this regard. Features detection stage along with projection stage is working on a frame rate of 15 to 20 frames per second. So a space exists for more algorithms to improve projections but it must be kept in mind that system should work at a frame rate of 10 to 15 frames per second.

This project can be extended to many applications i.e. eye-gaze based interfaces, appliance control. Project is developed in C/C++ using OpenCV library and availability of OpenCV library for different operating systems like MS Windows, Macintosh and Linux, has made the task simple to extend this project to different operating systems.

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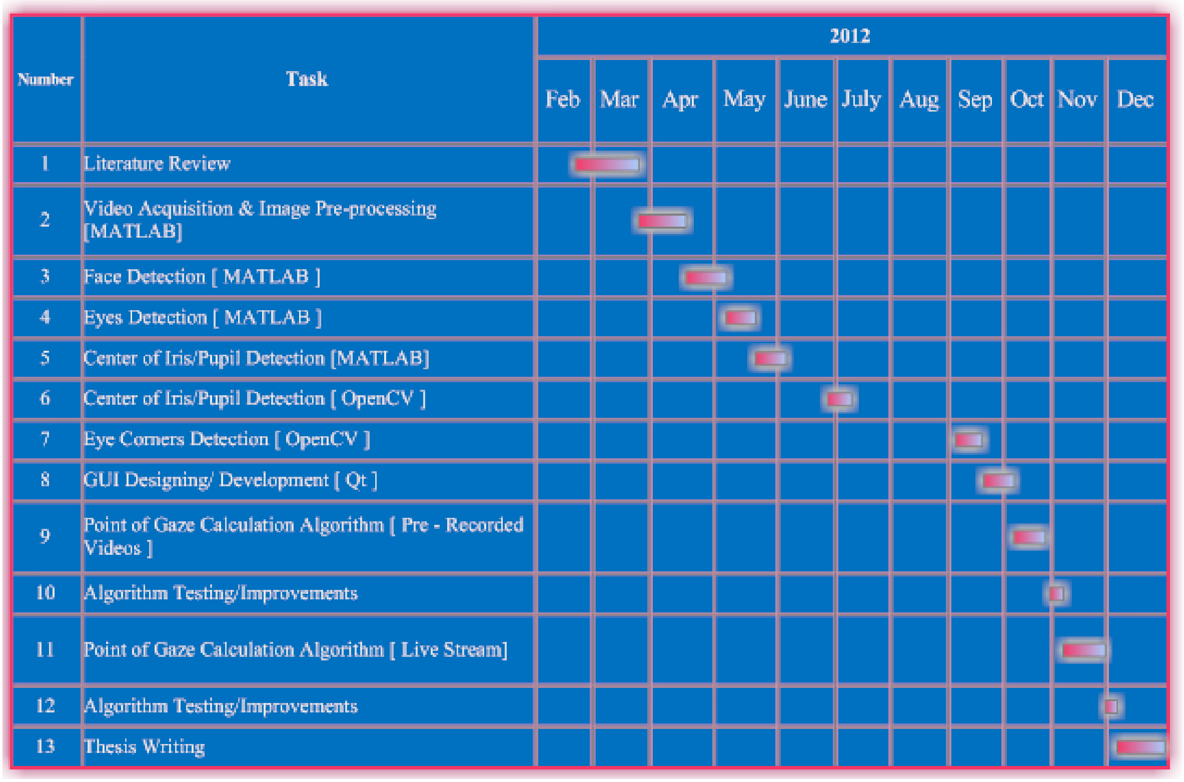
Appendix A: Project Timeline

DATE	January 14,2013

PROJECT ID	22	**TOTAL NUMBER OF WEEKS IN PLAN**	43

TITLE	GazePointer: A Real-Time Mouse Pointer Control Implementation based on Eye Gaze Tracking



Number	Task	2012										
		Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	Literature Review	■	■									
2	Video Acquisition & Image Pre-processing [MATLAB]		■	■								
3	Face Detection [MATLAB]			■	■							
4	Eyes Detection [MATLAB]				■							
5	Center of Iris/Pupil Detection [MATLAB]				■	■						
6	Center of Iris/Pupil Detection [OpenCV]					■	■					
7	Eye Corners Detection [OpenCV]								■			
8	GUI Designing/ Development [Qt]								■	■		
9	Point of Gaze Calculation Algorithm [Pre - Recorded Videos]									■		
10	Algorithm Testing/Improvements									■	■	
11	Point of Gaze Calculation Algorithm [Live Stream]										■	
12	Algorithm Testing/Improvements										■	■
13	Thesis Writing											■