Biometrics using Complex eye movements

By

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Dedication

To my parents and that one person because of whom I decided to stay and complete my MS degree.

Approval

It is certified that the contents and form of the thesis entitled "**Biometrics using Complex eye movements**" submitted by **Asfand Iar** have been found satisfactory for the requirement of the degree.

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Asfand Iar

Abstract

This thesis proposes a solution of how eye movement data can be used for biometric identification. Eye movement data have behavioral characteristics that are useful for biometrics. Different statistical features are extracted from eye movement data. These features are extracted from two main characteristics of eye movement data i.e. saccades and fixations. Different machine learning algorithms are used to train model on different set of features to come up with best possible combination that produces comparatively better accurate results. The thesis focuses on providing mechanism to convert available data into vector form such that machine learning algorithm can be trained over it.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Biometrics is a combination of two words i.e. bio and metrics. Bio means human and metrics mean to measure, therefore, biometrics refer to those metrics that are related to human beings. In field of computer science biometrics refers to those characteristics and properties that are used to identify human beings. There are many characteristics that are similar in all human beings. Rather than focusing on these characteristics that combines humans, biometrics focus on those features that set humans apart. Therefore, these metrics are some measurable parameters that can be used to describe and distinguish between different individuals [1]

As per another definition biometrics is the study of biological characteristics that can be measured easily. In field of computer science biometrics refer to the study of finding a way to authenticate different users. These techniques depend on certain physical characteristics for which we already know how to measure these. Also, this is important that the process of measurement is automatic [2]

Biometrics refers to some process or technique that can be used for access control and authentication process where every individual is expected to report by themselves. The basic theory is that everyone is unique and there exists certain physical and behavioral characteristics that can be measured. These characteristics must also support the theory and should be different from one individual to another.

In IT world, the term biometrics is used interchangeably for biometrics authentication. Biometrics authentication is used as security authorization process that is automatic and individual presence is ensured as well. Other type of security authorization processes like RFID cards or passwords fail here as any person can use these

techniques on behalf of other person [3]

The main question that comes into mind is that what are the biological characteristics? Below is a list of properties that need to be satisfied by any physical or behavioral characteristics before it can be classified as biometrics [18]

- Universality: The characteristics should be present in each and every person.
- Distinctiveness: The characteristics for two individuals should be different from one another.
- Permanence: The characteristics for same person should not be varying especially over time.
- Collectability: The characteristics should be quantitative There are certain other issues that must be considered as well for any characteristics to be used practically for biometrics.
- Performance: This term is used for the accuracy, resources required, speed, and some operational and environmental parameters required to measure the characteristics.
- Acceptability: Since the process involves individuals, therefore, it is an important aspect to keep in mind that how much acceptable the technique is to be used in their lives.
- Circumvention: This term shows to check that how easily the designed system can be fooled.

When the term biometrics is used, in field of IT, it is used as alternative of biometric authentication. This authentication is required to be met for providing access to information that is supposed to be only visible human itself. For information security there are certain requirements such as confidentiality, integrity, and availability [8]. There

are many other tools and techniques along with biometrics that can provide information security by meeting required criteria. Individual passwords, pin, verification via tokens are some of the other techniques that are used for information security and authentication purposes. To ensure the security criteria, often multiple techniques are combinely used because there are techniques to bypass these techniques. Biometric authentication process is supposed to be providing one to one correspondence and unbreakable technique for authentication and validation purposes.

Biometrics authentication and verification is important as the mechanism is supposed to be providing every individual a kind of identity management system that can be relied upon. The system is supposed to be working automatically so that there is no involvement from user in person because this is something because of which other techniques like pin and passwords mechanism fail over time [27].

1.1 Challenges

Often biometrics is the study of finding distinguishing features and characteristics among different human beings, rather than focusing on features that bring us together, biometrics mainly focuses on features that keep us apart. Most of the times biometrics is focused on physical and behavioral characteristics that set individuals apart from each other. Different works done so far focus on the use of physical characteristics for biometrics. Techniques used for fingerprint, facial structure, and iris recognition are examples of using physical characteristics for biometrics. These techniques are very practical and highly accurate, but are dependent on environmental factors. For instance, the way a finger placed on a sensing machine once can not be exactly the same as when placed the next time. Similarly face recognition becomes more difficult with increased chances of error due to many environmental factors such as pose of the person, light intensity, camera position, etc. Moreover, another major issue of these techniques is the huge amount of data generated. Usually in the form of a 2D

matrix, which leads to more data processing requiring more computational power. Thus, in summary there are two main issues with currently available techniques for biometrics:

1. Effects of environmental parameters
2. Large computational requirements for data processing

It is because of these issues that researchers are trying to find alternative techniques for biometrics. One approach is to replace physical characteristics with behavioral characteristics for biometrics in order to minimize the effect of environmental parameters. Moreover, the focus is to produce 1D data in order to reduce the computational power required for data processing.

1.2 Objectives

Researchers believe that eye movement can produce identifiable patterns that can be used to distinguish one individual from another. There are a number of physical and neurological features that can be extracted from eye movement data, which can then be used for biometric identification and verification. The data produced by this behavioral method is usually 1D data. Moreover, many of these features are similar for most people, therefore, can be ignored at the time of recording—further reducing the amount of data with only relevant features recorded and used for computation.

In summary, using eye movement data for biometrics address both aforementioned primary issues highlighted when using physical characteristics for biometrics. Therefore, this makes eye movement a potential behavioral characteristic that can be used for biometrics.

1.3 Main Contributions

Biometric is the study of finding distinguishing features among different human beings. Rather than focusing on characteristics that bring individuals together, the study of biometrics mainly focus on the features that keep them apart. There are multiple features and characteristics that differentiate one person from the other. Some of these include finger print, facial structure etc.

Fields like fingerprints have evolved over time and have become mature enough. These techniques are practiced in daily routine and used as distinguishing features.So far the techniques that have become mature enough to be used in practical are mainly focusing on physical characteristics. Whether that is fingerprints or facial recognition or any other characteristics. Although these techniques are providing quite good accurate results but still there are many dependencies as well which makes these techniques dependent on environment.

For example, the way finger is placed on sensing machine once can't be exactly the same as next time. Similarly facial recognition becomes even more difficult and chances of error also increase. It is dependent on pose of person, camera position, light intensity and many other things of this nature. Apart from environment the other issue with above mentioned physical techniques is that it produces matrix or 2-dimensional data. The data produced is huge and complex. This needs more computational power for data to be processed. In case an unknown person has to be identified from a collection of dataset present more complex computation will be required in order to perform this task.

Therefore, due to issues explained above researchers are trying to find alternative techniques that can replace physical biometric identification with behavioral biometric identification. Also, the researchers are trying to reduce data as much as possible so that the processing power can be reduced as well. Using iris color there is already research done. There are techniques that can be used to distinguish between gen-

ders of an individual. In other method described they can distinguish individual on regional basis using iris color such as Asian or African etc. In other technique both region and gender can be predicted accurately using iris color.

Now, iris color gives us distinguishing characteristics on a very broad level. Currently focus is on how this knowledge can be utilized to produce methods that can do identification of individuals. Rather than taking static iris color different features related to eye movement are recorded for a specific period of time.

Eye movement is a behavioral method and it also produces one dimensional data. Much of the characteristics are common for all individuals, therefore, these features are avoided. Only relevant features are considered for computation. There are many different tools available to produce data around eye movement of an individual.

Other behavioral method tried for biometric identification is sound processing. But since sound is also dependent on an individual's health and other parameters, therefore, the results are not that much promising. But still techniques tried in that area can be of great help to be used here. Since both methods are behavioral and produce less amount of processing data.

There are greater numbers of applications that can be produced once this technique becomes mature. Password and pin codes used as security for mobile phones etc. can be replaced by eye movement. Since it is more tedious to remember so many passwords for different applications and also there is a possibility that these passwords are hacked as well. Since eye movement directly relates to an individual, therefore, this technique will give more level of security.

In short, this new technique needs to be evolved because of so many promising features potentially present in it. Rather than physical characteristics focus is on behavioral characteristics. Amount of data to be processed is also lesser. There are many applications that can be made to replace identification tasks used in routine life with improved security.

1.4 Thesis Organization

In chapter 2 all the available techniques have been described. Also, pros and cons of these techniques are provided as well. In the end of chapter 2 the techniques applied so far on the problem that we worked upon was discussed in detail as well. Chapter 3 describes the work that we performed to design a solution for the problem. This chapter 3 describes each section in complete details. Then chapter 4 provides and discusses the results that we obtained by applying our approach. Also, this chapter 4 compare the results with techniques used by other people to solve the same problem. Next chapter 5 discusses different areas that impact the result if same algorithms are applied in practice. Last chapter 6 summarize the overall work and also discusses some areas where efforts can be possibly put in to improve current results.

Chapter 2

Related Work

We will start the chapter by discussing the work already done in different areas to provide solution for the problem. Also, we will try to provide the possible drawbacks or limitations associated against each technique. Below block diagram 2.1 will be a better explanation of a generic biometric system.

Biometrics techniques can be broadly divided into two categories.

1. Physiological Biometrics
2. Behavioral Biometrics

2.1 Physiological Biometrics

There are techniques that use physical characteristics for biometric identification and authentication purposes. Physiological is found more common in practice and is considered to be more accurate as well. Some of the physiological biometrics used in practice more commonly are: [5]

1. Fingerprint Recognition
2. Iris Recognition
3. Face Recognition
4. DNA Recognition
5. Hand and Finger Geometry Recognition

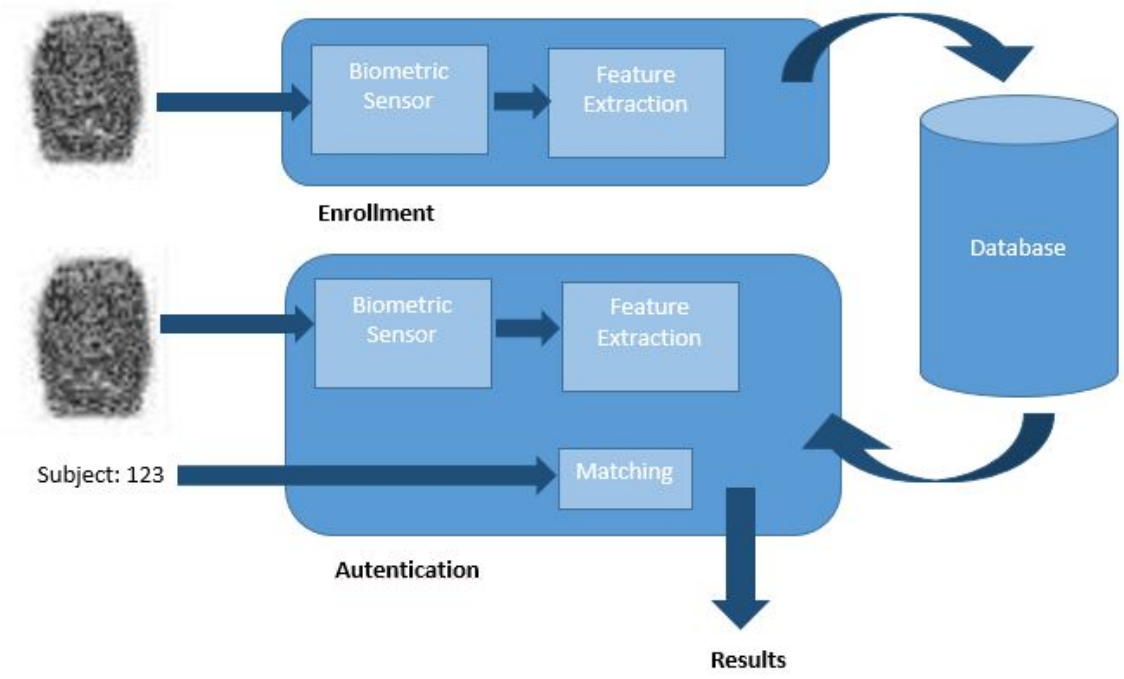

Figure 2.1: Block diagram of generic Biometric system

6. Palm Print Recognition

7. Retinal scan Recognition

2.1.1 Fingerprint Recognition

Fingerprint recognition is supposed to be widely used technique in this area. It is used as legally accepted method for biometric identification across the world [33]. The technique works around the fact that every person has got unique fingerprint [32].

Fingerprint is a low cost solution which is less intrusive at the same time as well. The technique is easy to deploy and start functioning soon. In situation where there is a need of remote setup for identifying the passing by crowd this property of easy deployment becomes important. This technique is easy to use and user friendly as well. Also, the option of using multiple fingers make this technique more flexible as

well [31].

A finger is considered to be made of different ridges and valleys. Ridges are the upper surface areas whereas valleys are the lower surface areas in fingers. Ridge characteristics are stored and are considered to be unique. There are five fingerprint patterns [31]:

1. arch
2. tented arch
3. left loop
4. right loop
5. whorl

Arch is the pattern from one side of finger to other side rising in the form of an arch in the centre. In loop a curve is formed on centre on the pattern from one side of finger to another side. Whorl forms a circular pattern surrounding a central point. Areas with lower curvatures and unusual combination of ridges are considered to be the point of interest and stored for every individual.The other point of interests in ridges are:

1. ridge ending
2. bifurcation
3. short edge or dot

The point at which ridge terminates is known as ridge end whereas bifurcation is the point where one ridge splits into two ridges. A dot or short ridge is the one that is relatively smaller than average length of a ridge [31].

These point of interests are stored initially for every individual. Then at the time of authentication, comparison of recorded one is made with this entry and decision is made automatically.

There are multiple issues reported with this technique. Three of main disadvantages are:

1. Vulnerable to noise and distortion brought on by dirt and twists.

2. Some people have damaged or eliminated fingerprints.

3. Using fake fingers by intruders.

The first two issues are common for all techniques using physical characteristics for biometrics. These characteristics change over time and at the same time are affected by environmental factors. The last disadvantage require serious attention. There are techniques used by intruders to bypass security systems that are using fingerprints for biometrics.

2.1.2 Iris recognition

For personal identification iris recognition is supposed to be the most accurate technique available. Therefore,this technique is in use where user access is restricted to authentic users like border control etc. [32].

Since iris has got some very useful and powerful characteristics that make it a strong candidate and that is the reason of its wide application in this area. It provides many interlacing minute characteristics such as freckles,crypts, strips, coronas, furrow etc. [15]. These characteristics also known as texture are supposed to be unique for each subject. For both eyes of a single individual or in case of twin siblings these properties are totally unrelated [11].

As per table 2.1 iris is the most reliable available tool as compared to other techniques available in the field. As discussed earlier as well that iris pattern for left and right eye both are different, thus using both separately for identification of same person provide a great level of freedom. Iris is supposed to be controlling the amount of light entering eyes through pupil. The formation of iris is highly randomized and that makes it a suitable candidate for biometric [10]. Below are some of features that make iris good candidate for biometrics [29]:

1. The difficulty of forging and using as an imposter person
2. It is intrinsic isolation and protection from the external environment
3. It's extremely data-rich physical structure

Now we will look how iris recognition system works. First a photograph is taken. Then for the iris region iris template code is generated. Then the generated code is cross verified against already stored template in database until one is matched or it is rejected in case no one matches. There are several methods such as Sobel Operator, Prewitt Operator, Canny Edge Detection, Roberts method and so on for accomplishing single task as edge detection.

Table 2.1: Biometric comparison List

Method	Coded Pattern	Misidentification	Security	Application
Iris Recognition	Iris pattern	1/120000	High	High security facilities
Finger printing	Fingerprints	1/1,000	Medium	Universal
Hand Shape Size	Length and thickness of hands	1/700	Low	Low security facilities
Facial Recognition	Outline,shape and distribution of eyes and nose	1/100	Low	Low security facilities
Signature	Shape of letters,writing order,pen pressure	1/100	Low	Low security facilities
Voice	printing Voice characteristics	1/30	Low	Telephone service

Below diagram 2.2 shows schematic approach for an iris recognition system.

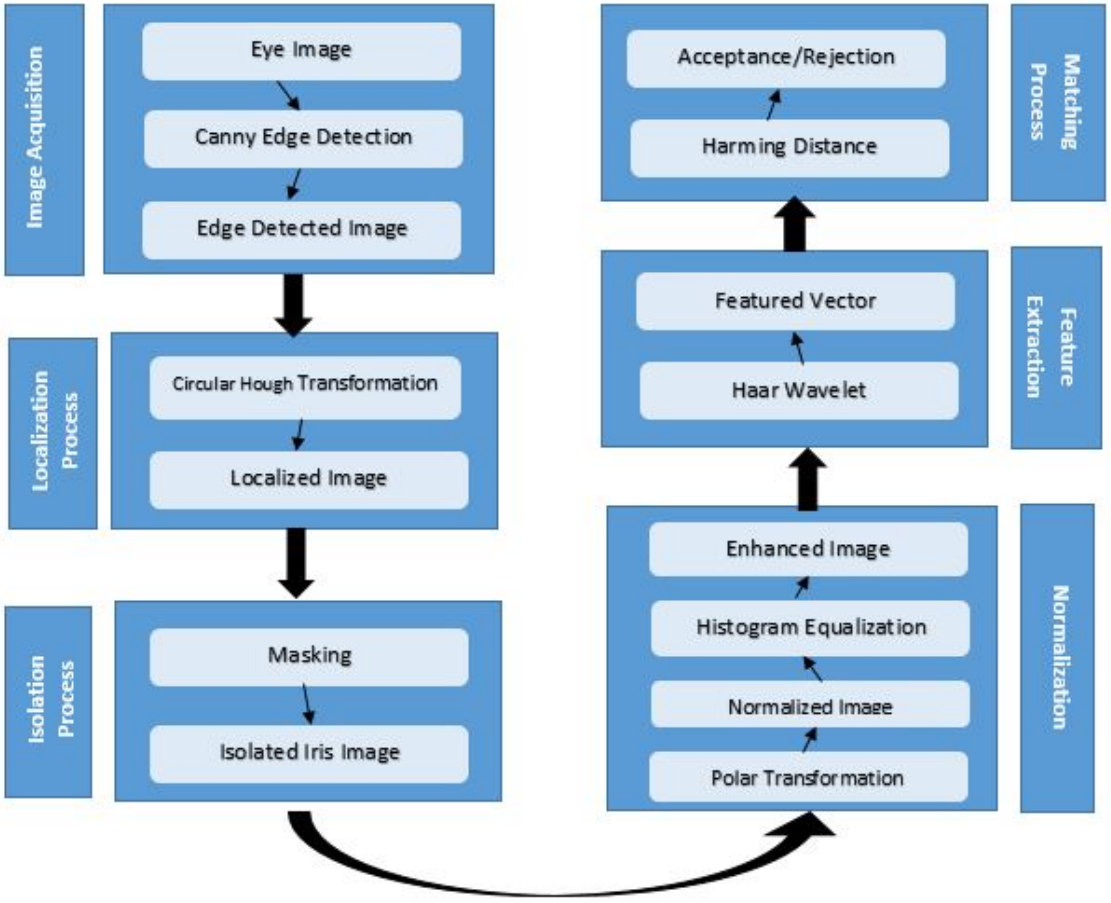

Figure 2.2: Block diagram of iris recognition system

2.1.3 Face Recognition

To recognize somebody , we normally use faces for recognition. Human beings look at face to distinguish one person from the other. Face as a whole provide us more information than just identification or recognition. For example, looking at eyes of a person one can easily say about how he/she feels. Facial geometry of unique features of face are extracted and stored. Face recognition technique is used by law enforcement agencies most commonly. The technology is non intrusive and cheap. The environmental features such as light intensity, camera positioning, person's orientation affects the overall technique [7].

It require camera as input to capture image. Since most of smart-phone devices, laptop, computers etc. have built in cameras, therefore, this technology can be easily deployed in any of these devices. Same technology is used by US driving licensees providing department for identification purposes. For researchers this technique has been found to be very challenging. But it produces very useful applications on the other hand. The implementation of the technique is very challenging. This is a type of computer vision in which face is used as main input for distinguishing among individuals. Below five steps are involved in complete process [23]:

1. Acquire image by taking live photo or scanning an old photograph.

2. Locate face within the image.

3. Analyze facial image for valleys and triangles to generate face print.

4. Compare face print with stored prints in database.

5. Make a decision about a possible match or no match at all.

Face recognition system is the oldest technique that researchers have been working on in this area. Researchers have conducted vigorously in this area for the past four decades or so. Though a certain level of maturity has been achieved already yet this technique is not capable enough to cater all kind of scenarios. The ultimate goal is to emulate human vision system and develop such algorithms that will act like humans [23]. A strong and coordinated effort is required by below feilds in order to achieve desired results:

1. computer vision

2. signal processing

3. psychophysics and neurosciences

There are several steps involved in recognition of a person using face. Initially human face is detected to limit the search space. Other steps are mentioned above as well. Below figure 2.3 shows overall process.

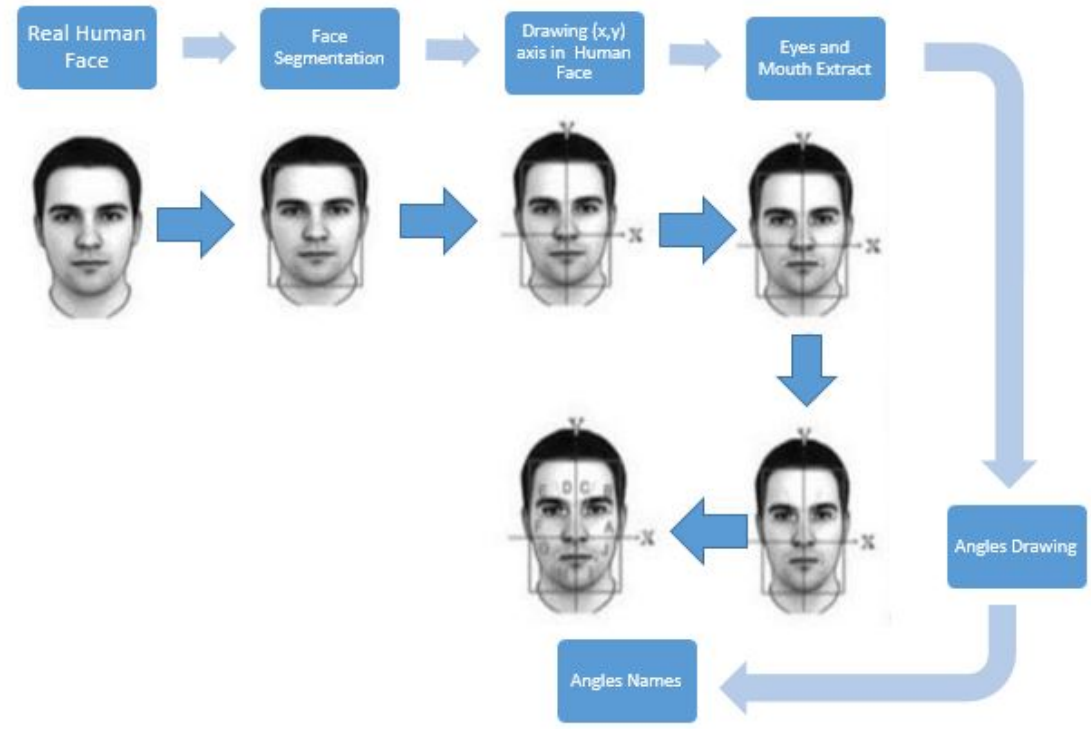

Figure 2.3: Face recognition system

2.1.4 DNA recognition

Since it is very difficult to acquire and analyzed DNA, therefore, its application is very limited in practice. However, using STRs (short tandem repeats) several times, the accuracy of identification has been proven to be increased. This technique enables the development of novel application of DNA based person identifiers (DNA personal IDs). Short tandem repeats (STRs) in the DNA base sequence are a promising informational source for personal identification. The authors previously generated a person identifier (DNA personal ID) by arranging repeat counts in two or more STR positions (loci) in predetermined order and constructed several basic experiments to investigate practical applications. The present paper proposes a biometric identification system and a biometric signature system based on the DNA personal ID. A method of identification using two ID cards was developed as a transitory measure until a real-time DNA analyzer can be developed [17].

Evolutionary trees can be constructed from the information that can be extracted from DNA sequence. There are several methods to do this task such as:

1. Distance matrix
2. Parsimony
3. Likelihood method

Distance method has the disadvantage of reducing the information of two dimensions into one parameters which cause loss of information. The advantage of this method is that it can be implemented easily.

In short we can summarize it as there is a potential in this domain to be used as solution for biometrics. There are techniques that can be used to generate the kind of data that will be helpful for biometrics. Also, there are solutions that can be deployed to automate this process of biometric authentication. The main problem is

the difficulty in acquiring the data and analyzing it later on. These issues make it inappropriate for biometrics and limit its application to special purposes only [13].

2.1.5 Hand and Finger Geometry Recognition

A number of measurements are taken from human hand which are then used to identify that person. These measurements may include:

1. shape
2. size of palm
3. Length of fingers
4. widths of the fingers

The technique has got some other properties as well such as it is very simple, inexpensive and easily usable. Other environmental factors also do not have much impact on the system. The factors include dry weather, dry skin, individual's health, atmosphere temperature etc. A simple digital camera can be used to obtain the image which is a lower cost apparatus for obtaining he data. The other techniques require high cost apparatus for obtaining input data. Since it doesn't require any such details that are questionable, therefore, user acceptability is also on higher side. Some of the strengths can be described as follow [4]:

1. Ease of use
2. Resistant to fraud
3. Template size

The performance can have impact if people wear extra items like big rings, swallow fingers etc. There are ways to deceive the hand systems such as sophisticated bone structure models of the authorized users. Paralyzed and Parkinson's disease affected people will not be able to use this biometric method [34].

2.1.6 Palm Print Recognition

Inner part of a person's hand is known as palm print. Over a period of time, this has been believed that with the help of these prints one's future can be predicted. Recently people have started to think that this information can also be used for biometric identification. Palmprint is supposed to be reliable because it contains more characteristics than other modalities.

It is unique for each person yet this property is universal for all people as well. Palmprint recognition is applicable in many areas such as civil applications, law enforcement etc. Palm has certain features that make it a good candidate for biometrics such as:

1. geometric features
2. delta points
3. principal lines
4. minutiae
5. ridges
6. creases

There are three principal lines comprising three regions. From palmprint principal lines, minutiae, ridges features can be extracted for identification. There are two main approaches followed for palm print recognition. One approach depends on lowresolution characteristics whereas next approach is based on high-resolution features [21].

2.1.7 Retinal scan Recognition

The concept of retinal scanning is very old. Even research done way back in 1930's show that blood vessel in back eye has the tendency and is unique in each individual. A company named EyeDentify in 1984 designed and developed initial retinal scan system.This system was used for commercial purposes. After that there has been many addition to the field which resulted in more accurate and applicable systems.Initially large amount of time was required for each processing but with increase in processing power of processing units this time has reduced a lot [12].

Although this method is the most reliable one, yet it has got some disadvantages. First we need to know how to take a snapshot of the eye and what are the steps involved in passing light through eye. This will make easier for us to understand the way retinal scanning works.

Retinal scanning involves the reading of vascular patterns found on the back of the eye. This method requires light to pass through each physiological layer of the eye that provides vision. The following segment will walk us through the path of light as it enters the eye, on its way to the retina.

The most current technology involves three steps in executing a retinal scan as described below.

1. Image is acquired by taking a photograph.
2. Different sizes of the blood vessels are summarized into a pattern.
3. Obtained pattern is checked and verified against already stored patterns in database.

2.2 Behavioral Biometrics

There have been issues identified with techniques that uses physical characteristics for biometrics. These techniques are very practical and highly accurate, but are dependent on environmental factors. For instance, the way a finger placed on a sensing machine once can not be exactly the same as when placed the next time. Similarly face recognition becomes more difficult with increased chances of error due to many environmental factors such as pose of the person, light intensity, camera position, etc. Moreover, another major issue of these techniques is the huge amount of data generated. Usually in the form of a 2D matrix, which leads to more data processing requiring more computational power. Thus, in summary there are two main issues with currently available techniques for biometrics:

1. Effects of environmental parameters
2. Large computational requirements for data processing

It is because of these issues that researchers are trying to find alternative techniques for biometrics. One approach is to replace physical characteristics with behavioral characteristics for biometrics in order to minimize the effect of environmental parameters. Moreover, the focus is to produce 1D data in order to reduce the computational power required for data processing.

Below are some of techniques on which work has been carried out to design a solution for biometrics:

1. Voice recognition
2. Signature recognition
3. Eye-movement recognition

2.2.1 Voice recognition

Voice is a supposed to be a combination of having both physiological and behavioral charecteristics. Some of the features dependant on physical characteristics. These features include vocal tracts, mouth, nasal cavities and lips that are then used for generating voice. The features are based on the shape and size of the appendages. These characteristics of human speech are invariant for an individual. The behavioral part is not that much static and changes over time. Main reason for these changes are due to age, medical conditions and emotional state etc.

For large scale identification voice is not supposed to be helpful since it is not distinctive that much. A fixed predetermined phrase reading is categorized as text-dependent voice recognition system . On the other hand if text is not fixed then this text-independent voice recognition system can be utilized to recognizes the speaker no matter what the user speaks. There are two major approaches that can be used for biometrics while working with voice recognition [26].

1. Automatic Speaker Verification (ASV)

2. Automatic Speaker Identification (ASI)

A disadvantage of voice-based recognition is that speech features are sensitive to a number of factors such as background noise, speaker's health etc. This impact of environmental factors make it more close to physiological biometrics rather and thus this technique faces similar kind of issues that were discussed earlier.

2.2.2 Signature recognition

Signature and the way a person signs is considered to be his personal attribute. It is also considered that another person can't create exact copy of that or even closer to it. Although, some manual effort is required in recording the data, yet it is used practically in government, legal, and commercial transactions as a way of identification and verification. Signatures are a behavioral biometric but yet changes over time and also depends on some physical characteristics like type of pen used, paper quality, emotional situation of signatories etc. Other issues seen with this technique are:

1. Signature from same person an vary substantially and it is difficult to link them together as one person did those.

2. Professional forgers can reproduce signatures and bypass easily.

Unlike other techniques that requires special type of sensors to record data, signature technique does not require any special tools for this purpose except a pen and paper.Other big advantage seen with this technique is that it is callable [24]. If we consider a scenario where biometrics data is leaked and we need to change the data. For most of the techniques it is not possible and thus this is a risk. We need to have such options where users can change the input in case of such incidents which has possibility and can happen. Thus signatures data can be changed and using same technique new signatures can be reproduced. Thus same techniques will be in place and no major changes will be required to recover security system with fresh and new data [24].

Among all of the techniques developed and tested in practice for biometrics, automatic handwritten signatures are most legally and socially accepted technique. The most challenging aspect is to obtain high accuracy results as well as avoid false authorization or rejections.

The system is based on handwritten signatures that are used for signature verification and signature identification. A decision is made by the system Whether the given signature belongs to a particular person or not. These systems can be of two kinds.

1. Static i.e. only the digital image of the signature is available
2. Dynamic i.e. signatures are acquired by means of a graphic tablet or a pen-sensitive computer display

A signature creation process includes signer's brain as a motor control program. This is implemented through the neuro-muscular system and then placed on the writing surface with the help of a handwriting device [28].

Signature verification examine the way a user signs something that he/she wants to be used as their identification code or secret [25]. Multiple other features can also be associated with dynamic verification process that includes speed, acceleration, velocity, and pressure etc along with completed signature's static shape. Actually this is not a biometric technique but still can be treated as one since it is the behavior of an individual the way a user signs. Below is a block diagram 2.4 of automated signature verification system.

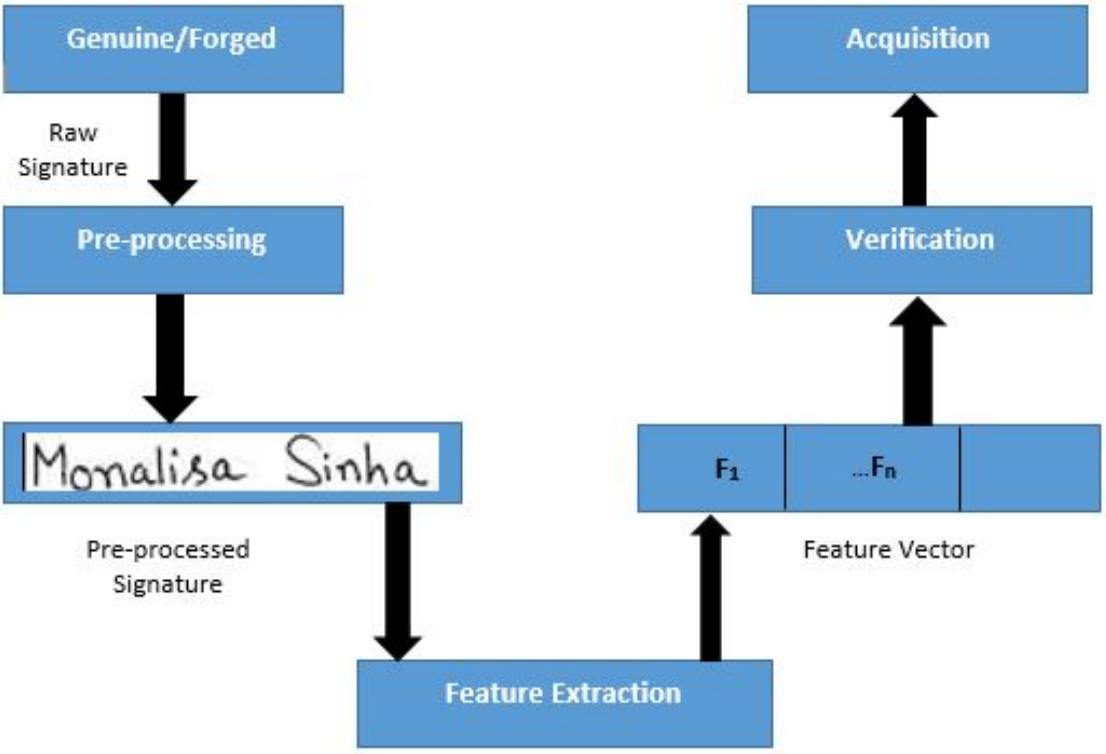

Figure 2.4: Automated Signature Verification System

2.2.3 Eye-movement recognition

Initially, the idea that eye movement data can be used for biometrics was presented by Kaprowski and Ober [20]. In their work, they record eye movements for different people looking at jumping dots on a screen, and demonstrate that eye movements can potentially be used for biometrics. They extract different features from eye movement to train a model using different machine learning algorithms including C4.5 decision tree, KNN, and SVM.With the help of this method, the sensor records human's eyes reaction for visual stimulation. Eye movement tracking systems record the stimulus while human eye tries to follow moving dot on the screen. The method used in this paper [20] has got several advantages. It combines behavioral and physiological aspects. Thus it is difficult to bypass this system. Also it provides the ease to perform both operation simultaneously and combine it with other available techniques.

In [6], the authors extend the previous work done using recording for jumping dots on screen to recording and analysis of eye movements on text reading. They combine different features using FTT and PCA, as well as, observe that the inclusion of eye gap—distance between two eyes—produce better results. Although, distance between eyes is not related to eye dynamics, but still their results show a positive impact on obtained results. Data for twelve participants was processed for both moving object and text reading. Accuracy was increased and an overall approach was designed that can cater object viewing as well.

In a recent work, Holland and Komogorstov [16] extract several features from eye saccades and fixations—eye fixations are the pauses at different points of interests whereas eye saccades are the quick movements between fixations or point of interests. The authors discuss the idea that saccades and fixations can be used as basis for features extraction. Currently, most of the works are centered on extracting statistical features using these two characteristics. Different combination of features are extracted from saccades and fixations, which in turn are used for further processing. In this paper [16], several related topics were discussed.

1. Viability of CEM features
2. Techniques in a biometric context
3. Effects of stimulus type
4. Spatial accuracy
5. Biometric viability

Cantoni et al [9] proposed gaze analysis technique (GANT) for human identification, a graph-based representation of fixations. The technique built a fixation model that in turn is used to construct a graph. Afterward density maps are used to compute similarity between two recordings as done in the previous work. This paper [9] suggests a novel based technique named as GANT. A graph-based representation of fixation points that is recorded with the help of eye tracker during human computer is utilized. Main aim is to provide a demo that will represent that the way a person tracks the video or object is a distinctive feature for each individual.

Prior to BioEye 2015 dataset [22], most of the works done are based on smaller datasets. Moreover, these datasets do not take into consideration template aging effect. However, the much recent BioEye 2015 dataset provides a larger dataset that also considers the template aging effect. Moreover, the dataset is publicly available, and is used for BioEye 2015 competition.The competition was organized to boost up this way of biometrics. The competition was focused to the issues faced by researcher such as:

1. quality of the eye movement recordings
2. different visual stimulus types
3. the effect of template aging on the resulting recognition accuracy

Competition provided database that contains:

1. records from 306 subjects

2. stimulus of two types

3. recordings separated by short-time and long-time interval

Now we will talk about some of the work done by top ranked people who participated in this competition. The work [30] ranked first in the competition extracts statistical features such as velocity and acceleration from saccades and fixations, which then are used to train a model using different machine learning algorithms. As per the results, model trained using neural networks produce the best results. The algorithm that was developed did not take into account the available information like provided validity and the stimulus position. However, it make use of the information that there is in unlabeled data there is one entry for each subject.

Furthermore, the technique proposed by Narishige Abe [14] stood 2nd in the competition. The technique divides the data into local blocks to extract a feature vector composed of saccades and fixations duration, frequency, and acceleration. To test their solution on unseen data, one to one correspondence is done to make predictions. The third ranked work by Pawel Kasprowski [19] extracts jerk along with velocity and acceleration as part of input vector. In addition to these features, a histogram of various bins for data related to text reading is also extracted. The authors then use SVM and random forest algorithms for training the models.

All works described above show that the main focus is around two characteristics, the saccades and the fixations, to extract all the statistical features. These features include position, displacement, velocity, acceleration, jerk, and frequency. Once the feature vectors are constructed for each input file, then different classifier algorithms, including KNN, SVM, neural networks, and random forest tree, are applied to train the model.

Researchers believe that eye movement can produce identifiable patterns that can be used to distinguish one individual from another. There are a number of physical

and neurological features that can be extracted from eye movement data, which can then be used for biometric identification and verification. The data produced by this behavioral method is usually 1D data. Moreover, many of these features are similar for most people, therefore, can be ignored at the time of recording—further reducing the amount of data with only relevant features recorded and used for computation.

In summary, using eye movement data for biometrics address both aforementioned primary issues highlighted when using physical characteristics for biometrics. Therefore, this makes eye movement a potential behavioral characteristic that can be used for biometrics.

Chapter 3

Proposed Approach

In the proposed solution, eye movement data for each recording was converted into a feature vector. These feature vectors were then combined to form an input file used to train the model. Afterward the trained model was tested on unseen data to check its accuracy. Figure 3.1 illustrates different stages of proposed solution.

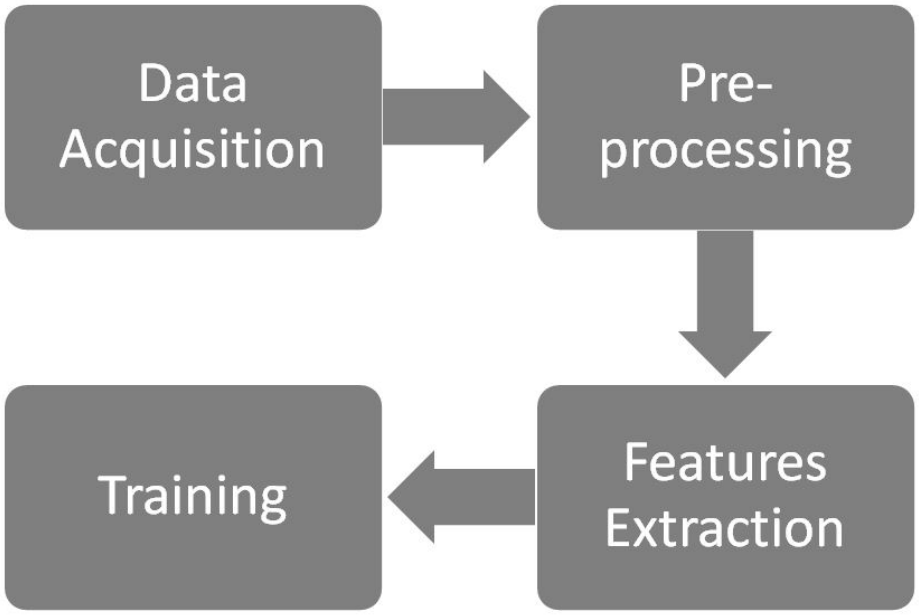

Figure 3.1: Block diagram of the proposed solution

3.1 Data Acquisition

We used publicly available dataset [5] for our work. The dataset is generated by passing each individual through a recording session. For each recording session an

input file is generated. The file contains x-axis and y-axis positions for both left and right eyes at each millisecond. Furthermore, there are several other features that are also recorded; however, only the relevant ones are stored and the rest are ignored during the recording process.

3.2 Preprocessing

The initial data files contain many missing values. These missing values are represented by NaN. Since the proposed method dealt with numeric values, we converted these NaN values to some numeric form. We tried several options to replace these values. Initially, we replaced NaN with a default value of 0. Next we tried to estimate an average value based on its temporal neighborhood such as 10, 20, 30, 40 and 50 respectively. For each missing value a new value was estimated using specified number of neighbors. All neighbors were treated equally weighted. We did not use any weighting that make closest neighbor more important by assigning it more weight as compared to neighbors that are located farther.

The next option we tested was to ignore the tuple with NaN value. Any row in the recording session that was having that was having at least one of its column as NaN was ignored. The rest of data in the file now contain only numeric values. This data was treated as input for the next phase.

3.3 Features Extraction

In this phase, the pre-processed files for recording sessions were taken as input. Features were extracted taking into consideration the main characteristics of saccades and fixations. Each input file was then divided into local blocks that were a representation of fixations. The difference in features of consecutive blocks was considered as features for saccades. For each block different statistical features were extracted

including displacement, velocity, and acceleration. As by definition velocity is the rate of change of displacement with respect to time and acceleration is rate of change of velocity with respect to time, therefore, the two features are redundant and only one of these can be used for analysis. Furthermore, the data files for the recording sessions contain x-axis and y-axis position for both left and right eyes at every millisecond. The recording sessions were conducted by displaying two type of inputs on screen to individuals:

1. Jumping dot
2. Reading text

Since the nature of approaching both kind of input on screen was different, we split the files into two categories based on the kind of input. We extracted features for these files separately, and generated two input files containing feature vectors for each kind. Moreover, while processing we found multiple files with data recordings specific to one eye were missing. We used this information to extract features only for the eye with recordings. Thus, we extracted features using both eyes for input files with both eye recordings, whereas for input files with missing eye recordings we used only one eye to extract the features. In addition to the above mentioned features, we computed eye-gap feature for each recording. Our evaluation showed that files with only one eye recordings had more variation in the computed feature.

We compiled different input files with different combinations of features. All of these features were extracted using matlab software. Each file generated for different kind of features was treated as input for the next phase.

3.4 Training

The input feature files compiled in previous steps were used in this phase to train the model. The main file was split into two sub files. One file containing 80 percent of

data was used to train the model. The other file containing 20 percent of data was used to test the accuracy of model. We used Weka software for training and testing purposes.

We tested different machine learning algorithms in combination to different type of extracted features for building the model. The algorithms used include KNN, Random Forest Tree and Neural Networks. We analyzed the results by testing the trained model on testing data.

Chapter 4

Experimental Results

The data used in this paper is same as training data provided by BioEye 2015 [5]. We split this data into training and testing data using an 80-by-20 ratio—80% of the data for training and remaining unseen data 20% for model testing. We implemented the work described in [33] to get baseline metrics. As per their work, we divided input into two broader categories as described in Section 3.3. Thus we prepared an input feature vector file each for the moving dot and the text reading recording sessions. The accuracy of our baseline results was 22.02%.

During pre-processing stage results were computed by replacing NaN values using different option as described in 3.2. For rest of stages work described by [33] was implemented. The results produced by replacing NaN with a default value of 0 were comparatively better as shown in below Table 4.1.

Table 4.1: NaN Values Replacement results

NaN replacement	Accuracy
Default value of 0	0.2202
Using 10 neighbors	0.1958
Using 20 neighbors	0.1904
Using 30 neighbors	0.1908
Using 40 neighbors	0.1824
Using 50 neighbors	0.1816
Ignoring NaN tuple	0.1226

As described in the previous sections, we carried out our analysis using different

combinations of input features and machine learning algorithms to come up with comparatively better results than our baseline. In 3.3 different input files were compiled by extracting different kind of features. Displacement and velocity for single eye produced comparatively better results. Then in next phase 3.4 different kind of machine learning algorithms were used to compare the results.

The accuracy obtained by implementing work of [33] was 22.02% which was treated as baseline result. The accuracy produced using displacement and eye gap feature on data for one eye only with random forest tree using 100 number of trees as machine learning algorithm was 28.88%. Due to the point that data for one eye was found missing in files, eye gap feature cannot be computed for those files, we prefer not to use this feature. Thus the results that were obtained by only using displacement feature for one eye data in combination of random forest tree using 100 number of trees produced accuracy of 28.15%. Table 4.2 shows the accuracy for different combinations.

[1] Baseline results.
[2] Data for one eye was processed.

Table 4.2: Accuracies for different input and algorithms used

Extracted Features	Classifiers	Accuracy
Displacement	Random Tree	0.1926
Displacement	KNN with 5 neighbors and no weighted distance	0.1284
Displacement	KNN with 5 neighbors and 1/d weighted distance	0.2202
Displacement	KNN with 10 neighbors and 1/d weighted distance	0.2108
Displacement	Random Forest Tree with 100 number of trees	0.2202
Displacement	Random Forest Tree with 180 number of trees	0.2110
Velocity and acceleration[1]	Neural Networks	0.2202
Displacement and Eye gap	Random Forest Tree with 100 number of trees	0.2298
Displacement and Eye gap[2]	Random Forest Tree with 100 number of trees	0.2888
Displacement[2]	Random Forest Tree with 100 number of trees	0.2815

Chapter 5

Discussion

The main progress done in this field is by organizing the Bio-eye competition and providing dataset to public audience. Now, researcher can utilize the same dataset where they can apply their own techniques. This idea has got theoretical basis but the difficulty was that of availability of public datasets.The competition procedure is clear enough and provides the mechanism of how results are compiled. The results obtained so far making use of this dataset shows that relatively higher level has been achieved.Also, the progress made so far is encouraging and this is a good sign for the future of eye driven biometrics.

Also, this should be taken into consideration that the available dataset is dependent on the recording tool. So some mechanism needs to be in placed which can ensure that the developed technique work in the same way for data recorded using other tools. One other area is that this information was available that for every labeled record an unlabeled record is present in unseen dataset. This information can be utilized just for getting good results at the competition but can be misleading if the same algorithm is applied in practice.

In real world there are much more challenges. The recording places will be multiple. Number of subjects (people) will be much bigger as well. Recording devices can vary with usage even if same company's devices are used.Also, the way results were compiled in the competition were based on how much true classifications were made. In practice, it is more important to look at how much a subject was rejected falsely because this make the whole process ambiguous.

The work of the participants shows that main focus is on the features that can be

extracted from the available data which help in better categorization of the subjects. Among these features, the ones producing comparatively better results are

1. duration
2. position
3. amplitude
4. velocity
5. acceleration

However, it is also believed that some features can be extracted from the spectral analysis which can be used further to convert it into some valuable information. It is important to mention that the competitor providing best results for last year focused on using pattern recognition/machine learning framework and give this area more importance as compared to feature extraction. Further investigation is required in this area to improve overall accuracy of the eye movement biometrics methods. Our work is mainly focused on this area and used same features as extracted by them.

On different algorithms impact of the template aging was also evaluated. This was also missing before data provided by this competition which is considered to be an important parameter for biometrics. Also, recordings with multiple duration were made available. These are important aspects that needs to be considered while evaluating any algorithm designed for biometrics.

There were two different kind of inputs provided to users for which data was recorded i.e. one for jumping dot and other for text reading. However, the participants modified their algorithms and extracted features for both type of inputs. Additional datasets usage helped further in facilitating the analysis of the algorithms developed already.

Also, unlabeled recordings were captured in a different timings than the timings in which the original datasets were captured. This is therefore necessary that these

factors are considered while evaluating the algorithms for solving the problem to come up with more reliable solution given the requirement of making use of the exact same algorithm, that can be used as universal solution and not it is possible and not data specific.Also,the underlying algorithms can be fine-tuned And accuracy can be increased further.

Chapter 6

Conclusion and Future Work

This thesis proposes a framework to use eye movement data for biometrics. The proposed solution presents a technique to extract statistical features from saccades and fixations. The work also highlights the impact of missing data values on the results. Also, the use of complete data for one eye showed better results as compared to when using incomplete data for both eyes. Furthermore, the model proposed requires less computational power as compared to the previously proposed solution using neural networks and KNN etc. The improvement in results will encourage researchers that there is a potential in the field which needs to be explored further. Further work in this area will certainly lead to an increase in accuracy of the intended solution; in turn, making the solution feasible for practical use.

We have noticed a specific trend in the results that the accuracy for those subjects whose training records were more than five for both jumping dot and text reading were high. The number of subjects satisfying this condition were less than 30. Now, this give us an idea that for training purposes more recording sessions need to be considered. Also, in our findings we found that complete data for one eye is more valuable than incomplete data for both eyes. Therefore, it is required to make sure that missing data is as minimum as possible during the recording phase. The data provided to public is limited to be recorded by one tool and setup but in future to test the solution for more generic results multiple tool need to be used for recording purposes.

In current work, main focus is on extracting statistical features from two main characteristics i.e. saccades and fixations. It is therefore required not to only look

for other features that can be extracted from these two characteristics but it is also necessary to look for characteristics other than these two. In this way these new characteristics and the features extracted from these will contribute in uniquely identifying the subject.

The machine learning algorithms are used as per their definition in the work done so far. Since, modified versions can be used to check the performance. By this we mean that little modification to original machine learning algorithm can also be tested and check whether it improves the overall accuracy or not.

In future, no information should be given regarding unlabeled data. Since use of that information can provide extra benefits for the competition but in practice this information is not available. Thus any solution that is ranked top in the competition can then be checked in practice for same kind of behavior as well.

References

[1] Biometrics. https://en.wikipedia.org/wiki/Biometrics. Accessed: 2016-07-25.

[2] Biometrics. http://www.webopedia.com/TERM/B/biometrics.html. Accessed: 2016-07-25.

[3] Biometrics. http://searchsecurity.techtarget.com/definition/biometrics. Accessed: 2016-07-25.

[4] Supreet Kaur Gujral Amandeep Kaur Bhatia. Authentication using hand geometry and finger geometry biometric techniques.

[5] V Arulalan, G Balamurugan, and V Premanand. A survey on biometric recognition techniques. *International Journal of Advanced Research in Computer and Communication Engineering*, 3(2):5708–5711, 2014.

[6] Roman Bednarik, Hana Vrzakova, and Michal Hradis. What do you want to do next: a novel approach for intent prediction in gaze-based interaction. In *Proceedings of the symposium on eye tracking research and applications*, pages 83–90. ACM, 2012.

[7] Renu Bhatia. Biometrics and face recognition techniques. *International Journal of Advanced Research in Computer Science and Software Engineering*, 3(5):93–99, 2013.

[8] Debnath Bhattacharyya, Rahul Ranjan, Farkhod Alisherov, and Minkyu Choi. Biometric authentication: A review. *International Journal of u-and e-Service, Science and Technology*, 2(3):13–28, 2009.

[9] Virginio Cantoni, Chiara Galdi, Michele Nappi, Marco Porta, and Daniel Riccio. Gant: Gaze analysis technique for human identification. *Pattern Recognition*, 48(4):1027–1038, 2015.

[10] Vanaja Roselin E Chirchi, Dr LM Waghmare, and ER Chirchi. Iris biometric recognition for person identification in security systems. *International Journal of Computer Applications (0975–8887)*, 24(9):1–6, 2011.

[11] John Daugman and Cathryn Downing. Epigenetic randomness, complexity and singularity of human iris patterns. *Proceedings of the Royal Society of London B: Biological Sciences*, 268(1477):1737–1740, 2001.

[12] Kresimir Delac and Mislav Grgic. A survey of biometric recognition methods. In *Electronics in Marine, 2004. Proceedings Elmar 2004. 46th International Symposium*, pages 184–193. IEEE, 2004.

[13] Ayhan EMRE. Biometric security technologies.

[14] Anjith George and Aurobinda Routray. A score level fusion method for eye movement biometrics. *Pattern Recognition Letters*, 2015.

[15] Peter W Hallinan. Recognizing human eyes. In *San Diego,'91, San Diego, CA*, pages 214–226. International Society for Optics and Photonics, 1991.

[16] Corey D Holland and Oleg V Komogortsev. Complex eye movement pattern biometrics: Analyzing fixations and saccades. In *2013 International Conference on Biometrics (ICB)*, pages 1–8. IEEE, 2013.

[17] Yukio Itakura and Shigeo Tsujii. Proposal on a multifactor biometric authentication method based on cryptosystem keys containing biometric signatures. *International Journal of Information Security*, 4(4):288–296, 2005.

[18] Anil K Jain, Arun Ross, and Salil Prabhakar. An introduction to biometric recognition. *IEEE Transactions on circuits and systems for video technology*, 14(1):4–20, 2004.

[19] Pawel Kasprowski and Katarzyna Harezlak. Using dissimilarity matrix for eye movement biometrics with a jumping point experiment. In *Intelligent Decision Technologies 2016*, pages 83–93. Springer, 2016.

[20] Pawel Kasprowski and Józef Ober. Eye movements in biometrics. In *International Workshop on Biometric Authentication*, pages 248–258. Springer, 2004.

[21] MV Kishore, D Naidu, N Aditya Sundar, and G Pandit Samuel. Enhancement of finger print image using fuzzy filter. *International Journal of Computer Applications*, 120(3), 2015.

[22] Oleg V Komogortsev and Ioannis Rigas. Bioeye 2015: Competition on biometrics via eye movements. In *Biometrics Theory, Applications and Systems (BTAS), 2015 IEEE 7th International Conference on*, pages 1–8. IEEE, 2015.

[23] Pramod Kumar, Mrs Monika Agarwal, and Miss Stuti Nagar. A survey on face recognition system-a challenge.

[24] Isao Nakanishi, Shigang Li, Shouta Koike, and Yoshio Itoh. *Dwt domain on-line signature verification*. INTECH Open Access Publisher, 2011.

[25] Vishvjit S Nalwa. Automatic on-line signature verification. *Proceedings of the IEEE*, 85(2):215–239, 1997.

[26] Srikanta Pal, Umapada Pal, and Michael Blumenstein. Signature-based biometric authentication. In *Computational Intelligence in Digital Forensics: Forensic Investigation and Applications*, pages 285–314. Springer, 2014.

[27] Sushil Phadke. The importance of a biometric authentication system.

[28] Réjean Plamondon. A kinematic theory of rapid human movements: Part iii. kinetic outcomes. *Biological Cybernetics*, 78(2):133–145, 1998.

[29] Ahmad Poursaberi and B Nadjar Araabi. Iris recognition for partially occluded images: methodology and sensitivity analysis. *EURASIP Journal on Advances in Signal Processing*, 2007(1):1–12, 2006.

[30] Ioannis Rigas and Oleg V Komogortsev. Current research in eye movement biometrics: An analysis based on bioeye 2015 competition. *Image and Vision Computing*, 2016.

[31] V Sravya, Radhakrishna Murthy, Ravindra Babu Kallam, and B Srujana. A survey on fingerprint biometric system. *International Journal of Advanced Research in Computer Science and Software Engineering*, 2(4), 2012.

[32] Himanshu Srivastava. Personal identification using iris recognition system, a review. *International Journal of Engineering Research and Applications (IJERA) ISSN*, pages 2248–9622, 2013.

[33] Ravi Subban and Dattatreya P Mankame. A study of biometric approach using fingerprint recognition. *Lecture Notes on Software Engineering*, 1(2):209, 2013.

[34] Peter Varchol and Dusan Levicky. Using of hand geometry in biometric security systems. *RADIOENGINEERING-PRAGUE-*, 16(4):82, 2007.