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Machine Learning Algorithm to Identify Eye Movement Metrics using Raw Eye Tracking Data

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***Abstract*— Eye-tracking studies in software engineering are becoming more prevalent and also in the areas like medical, gaming and commercial fields. Researchers may use the same metrics but it is majorly used to give a different name for same field that cause the difficulties in comparing studies, so in this work, a model is developed to reduce the existing challenges. Many existing algorithms are available to apply on eye tracking data but machine learning is one of the best algorithms, for example random forest is one the machine learning algorithms, which helps to hold the test set. In the eye movement metrics, the dataset will be divided into two sets they are: test set and training set. This paper reports on the eye-tracking metrics using raw eye-tracking data. The proposed research work has used random forest, decision tree, KNN and SVM for experimentation in order to understand the dataset. The objective of this study is two-fold. First, the identification of various eye movement metrics events and Second, Apply visualization technique. It can be applied in medical field. Here first we will identify the accuracy, recall, precision and f-measure between KNN classifier and SVM, then identifying the eye movement metrics using machine learning algorithm. We give in this research a brief description of the eye movement metrics and which machine algorithm would give the best result, with its applications.**

Keywords*— *Eye tracking, Metrics, Fixation, Saccades, Visual perception component

I. INTRODUCTION

This section tells the brief idea about what eye tracking is and where it has been applied. Eye tracking is one of the best and unique methods that nobody can forge or copy from. The eye tracking technology is used in various fields like gaming, marketing, medical, visual system and commercial fields. Eye tracking which helps to monitor the eye location and activity based on optical monitoring of corneal reflections, and also analysis the eye movements and gaze positions in 2d and 3d environment. This process existed as early as 1800s, although major developments have been made in the last decade. In todays it is updates and used in industries such as gaming, research and medicine use this technology. The eye tracking technology have different devices to track, which are screen based or remote controlled or glasses. One of the popular technologies is Tobii technology, is applied in marketing, gaming and medical field. Where Tobii technology have various devices like Tobii pro fusion - which is screen-based eye tracker, it will capture the eye gaze at speeds up to 250 Hz, Tobii pro glasses 2- which is wearable eye tracker designed to capture real-world viewing behavior. This technology has various types of eye tracker they are, Spectrum Tobii pro, Tobii pro laboratory, Tobii pro VR analytics, sprint, Tobii pro Nano, Tobii pro X3-120.Most eye tracking systems are head-mounted and some work remotely and control the eyes automatically during motion.

Eye tracking technology uses a various type's algorithm but machine learning algorithms is one of the perfect algorithms to perform. To ensure the proper estimation, the data can be divided into two subsets, the training set and the test set. There are various machine learning algorithms for the classification of the dataset, such as KNN, SVM, naïve Bayes, decision tree, random forest, linear regression and many others. Where random forest algorithms are best classification algorithms. We conclude that machine learning algorithms are best for identifying eye movement metrics.

Usually, the eye movements are divided into fixations and saccades. Fixation means when the eye focus pauses in a certain position and when it shifts to a certain position implies saccades. The results of both fixation series and saccade series are called as scan path. Fixations are those times when our eyes stop scanning or seeing about the scene or object. We can get the fixation from gaze points. Gaze points mean the intersection of the gaze direction with the surface of the object being viewed. Where fixations are constructed, with the help of different algorithms we can translate the sequence of fixation. It gives the plot that is where person is exactly looking at. Where saccades are not constant and it can be triggered. In saccades both eyes move in the same direction and we cannot change the end point of saccades when the eye is moving.

This technology is used in many areas like, Web usability, Gaming, Medical research, Commercial eye tracking and Education & learning. It is also used in marketing field. Where it is difficult to understand the consumers behavior, but using Tobii glasses it is possible to understand. It captures shopper's habitual and subconscious behavior naturally. As it is storing a data related to consumer needs, it is easy for seller to sale the products. Playing fruit ninja game with eyes using gaze pointer.

We find matrix accuracy and uncertainty using algorithms for machine learning, such as random forest, decision tree, KNN and SVM. After trying out algorithms for machine learning, we found that random forest and SVM would offer the best accuracy compared to other algorithms.

II. LITERATURE SURVEY

[1] This paper mainly focused on PyGaze. They explained about what is PyGaze, use of PyGaze and also, they explained python method. PyGaze is a python application allowing users to create tests. This includes

functions for making complex paradigms simple to apply. At least two external packets are required to detect an eye. One is for eye tracking coordination and one for phase experiments. PyGame and PsychoPy are the libraries for manipulating screen screens, keyboard, cursor, joystick and other external equipment as well as internal timing. But the drawback of PsychoPy is that it needs a graphic card that allows OpenGL drivers and multitexture. Pygaze tests, without an eye tracker attached, can be created and tested on a computer. They used the klieg algorithm to detect the saccades it identifies by calculating the velocity of eye movement based on multiple samples. They concluded that pygaze is the best software, and fills the gap between complicated programming and time-consuming. It provides the best eye tracking package to make.

[2] In this paper eye movement detection is the major role and it is performed on the events like fixation, saccade, and smooth pursuits. They mentioned about 2 algorithms of eye detection which were used for a long time, they are Dispersion and Velocity threshold based. Where dispersion algorithm helps to find out the fixation by a spatial criterion where the recorded gaze points can move and detect saccades, and 2nd algorithm used for detecting saccades by a criterion of the minimal velocity. The major drawback is that user is left with number of parameters which have to be adjusted based on eye movement data quality. There are many algorithms that are designed but only for specific problem. Compare to all those algorithms and research machine learning method is the best option to detect eye movement event detection. This paper goal is to build universal algorithm which could work with any type of the eye tracking data. They compare the performance of 10 machine learning algorithms on eye event detection task. They used eye tracker which is known as Eyelink1000 to record the eye movement data. They recorded eye data of humanities laboratory using monocular eye movement method [They used many featured by tobii]. The features were normalized by removing the mean and scaling to unit variance and data was spitted into 2 subsets 1. Training – it used 10 machine learning algorithms 2. Testing Based on classification performance of universal and specialist models shows that random forest [supervised classification algorithm] almost reaches expert performance. They concluded that Random forest classification algorithm is the best choice for event detection algorithm.

[3] In this paper they used raw gaze samples as belonging eye movement metrics. They used machine learning algorithm which is random forest algorithm. It is one of the best algorithms, it is used to detect the fixation and saccades. They explained some existing algorithms they are velocity-based algorithm which detects the saccades and dispersion-based algorithm which detects fixation. These two algorithms come with the thresholds which must be set by the user. They used random forest algorithms and they used seaborne to simulate tests. Data is divided into test set and training set. After instruction, they introduced classier optimization, which is to decrease the memory space of the classifier by removing unnecessary features and reducing the number of trees. He concluded that for classification efficiency, the machine-learning approach is better than hand-made algorithms, and it is also cheap to use.

[4] In this paper they mainly focused on fixation map that is how fixation map analyses, how to create fixation map and use of it. We addressed the area of interest and scope by setting a visual stimulus, and investigate the use of fixation charts to recognize and interpret large numbers of signs of eye movement. They collected data on eye movements from the national gallery for 3 months to record through an automated eye tracker and collected data on 5638 subjects. It was important to meet both the general and scholarly interest in the work because of the analysis and collaboration of these unwieldy datasets. They used versatile analytical visual tool and 3D gauzes to fixation. They created fixation map which starts with blank map of the stimulus presented. They concluded that fixation map is used to define various parameters of the eye movement trace and also useful techniques in the visualization and communication of large eye data sets.

[5] In this article, they proposed fixing algorithm taxonomy. Some areas and metrics, such as fastening and saccades were mentioned. These types of metrics must be identified for analysis where fixation recognition decreases the eye movement procedure size and complexity. Some poor algorithms may cause fixation error, thus ensuring a good identification algorithm for valid fixation and location of the saccades where the fixation identification taxonomy classifies the algorithm in respect of five spatial and temporal criteria. The spatial parameters separate the algorithm by speed, dispersion and field of interest where spatial principles define three requirements distinguishing between three main algorithm types. Speed based, scattered and area based. Area based. They mentioned speed-based algorithms and explained the identification of speed threshold and MIT. They finally explained the algorithm based on the area. Finally, they compared the character of the algorithm and said area-based algorithms are not very good to identify. After all, these inspectors will better inform others of their findings. In this paper, you have improved your understanding of the potential identifying algorithm that supports analysis of the state of the eye for scientific investigation, and development of systems and applications based on the eye.

[6] In this paper they mainly focused on different forms of behavior data, for example the different view of normal people and healthy people, men & women and professional art views and non-professional art views. They used voronoi method because it's a target and quantitative method for characterizing fixation density. Voronoi Method: - It's a quantitative and objective method for characterization of fixation density. Scan path: - provides both temporal and spatial domains information. Transform search paths to character strings and can be applied to different scanning paths. String analysis: Voronoi diagram: -it's a cell division of a region with specific points in that field. This paper has advantaged as a powerful means of determining the uniformity of the fastening densities and can create areas linked to fastening density using the voronoi process. In this paper they concluded that the voronoi method is best used compared to a visual assessment to find the fixation density.

[7] In this paper they focused on web designs that is improve of web sites using eye tracking methods. They collected two kinds of data they are, Behavioral data and Eye–movement data. In web sites before research

information categories were placed on their importance, frequency of use, and relatedness. Visual search takes two steps. They explained about visual search with the type's deployment of attention and targeted processing. They concluded that comparison visual search is required as eye movement event data are not absolute and need to compare with another data collected. So that eye tracking methods can be used.

[8] In this paper they explained about biometric identification. The purpose is to uniquely identifying a given individual. It used in criminal justice, corporate and personal security. They gave an idea how we can perform biometric identification like face, eye or ears, where eyes have the various features which can be unique. There are many eye tracking systems but some errors rates are produced by current methods so they decided to take a research on eye movement features. They presented information fusion which means combines the information obtained from different eye movements such as fixation counts, average fixations, duration, average saccades, saccades amplitude, and average saccades velocity. It gives the accuracy of biometric system. They concluded that scan path is best for biometric identification.

[9] In this paper they mainly focused on heat maps. They explained how heat maps are created and used. Heat maps are good for seeing the big picture and it is value for paper, Reports and presentations are condensed because of the large quantities. We concentrated on heat maps that maximize the use of eye tracking technologies. They have explained clearly how we can use the heat maps, where we should apply, what we don't look at, what we don't know they've filled up these gaps and how to use proper heat maps. To identify the fixation, they used duration and the dispersion threshold. They pointed out that when viewing the image, the attachment will be better than when reading the passage. The fixation based on the algorithm was attempted to change.

[10] This paper offers different approaches to interpret and view details eye movements. Such various visualization modalities include details on how the viewer analyses the knowledge using scanning direction, length pattern, heat map fixation and scope. Then clarify how they divide energy between items and what they spend more time on. You used MASSVIS dataset. The dataset was named without algorithm and a statistic attribute was applied. We can understand the various ways of visualization from this paper.

[11] In this paper they focused on eye gestures and applied where hands aren't free, for example a patient can't move their body, in that situation they can use eye gestures to move. They used SVM, KNN and decision tree for classifying the data. With the help of decision tree implementation, they predicted and filtered intentional and unintentional blinks. They explained about EOG which means blinks detection or it generated by saccades. They used microcontroller to capture the signals with the discrete wavelength transformation and dual free complex, EOG signals were collected, filtered and analysed. They conducted extraction of the function in MATLAB and it involves transformation of mean root, mean square and discrete wavelength. They gave a classification result of SVM, KNN and decision tree. They considered different kernels, different KNN setting and different tree settings to understand the accuracy of the dataset. In discussion of classification result they mentioned DT is best algorithm as KNN and SVM uses larger memory capacity. In result section they mentioned KNN is the 1st best algorithm with the 96.9 accuracy and svm-96.8 KNN, DT-95.4 Can be used in pilots, patients of neuromuscular disease.

TABLE I. COMPARISON OF POPULAR ALGORITHMS

Algorithms & Proposed Year	Efficiency	Achievements	Limitations
Velocity-based algorithms (2000) [5]	Efficient	It separates the fixation and saccades points based on their velocity.	Velocities remain in the same place because of noise eye tracker.
Dispersion-based algorithms (2000) [5]	Comparatively more efficient	It identifies the fixation as groups of consecutive points.	Use of two parameters that are highly interdependent
Hidden-Markov model fixation identification (2000) [5]	Comparatively more efficient	It uses the probabilistic analysis rather than a fixed velocity threshold	Implementing the re estimation procedure, which is both complex and tedious.
Area - based methods (2006)[6][7][9]	Comparatively Less efficient	It labels points within a target area as a fixation and outside of all target area as saccades.	Time consuming to identifying fixation

III. PROPOSED METHOD

The proposed system is illustrated in Fig. 1. We propose a method in which we use machine learning algorithms to find out the fixation, saccades and smooth pursuit from raw eye tracking data. The proposed system takes raw eye tracking data as the input where there are no labels on the gaze data. To this unlabeled data we apply K-Means algorithm to group the fixation and saccades. Then we label them accordingly using IDT algorithm. In order to confirm the efficiency of our labeling procedure we apply several supervised machine learning algorithms on the data set. Later we propose that the same system can be used to identify the eye tracking events in various applications such as Web page analyzer, medical applications etc...

A Algorithm:

Step 1: Callibrate the eye tracker in web gazer
Step 2: Collect the raw eye tracking data web gazer
Step 3: Using IDT algorithm find fixation and saccades
Step 4: label the data into fixations as 0's and saccades as 1's
Step 5: Cluster raw eye tracking data using K-means and do a cluster analysis
Step 6: On the labeled algorithm apply supervised machine learning algorithms such as KNN, SVM, Decision tree, Random forest
Step 7: Validate the classification by calculating performance measures

The proposed method works on two kinds of dataset which means metrics identified by using machine learning algorithms and manual identification. Then we applied k-means algorithm using elbow method found the best k-value. Later we applied KNN, SVM, decision tree and random forest machine learning algorithms to understand the efficiency of the dataset.

There are 1075 of observations in one dataset which is recorded by the website called web gazer. As the recorded data is raw data, we applied IDT algorithm for classification. Here the 1075 observations are divided into 2 classes named as 0's for fixation and 1's for saccades. Then the algorithms are evaluated using confusion matrix to understand the efficiency of dataset.

There are total of 49 observations of data which is collected from the same website where we collected Dataset 1, but we labeled the data by IDT algorithm but it describes machine learning algorithm is better than the manual identification. Here the 49 observations are divided into 3 classes named as fixation, saccades and smooth pursuit. We use confusion matrix to calculate the accuracy of the system.

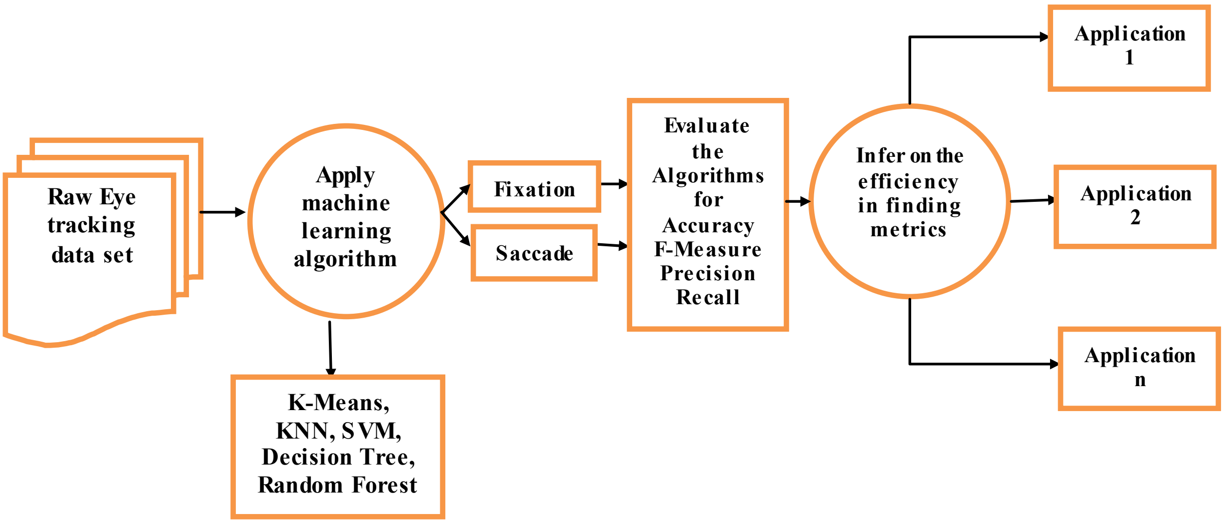

Fig. 1. Proposed Method to find eye movement events using machine learning to help applications that use eye tracking

IV. EXPERIMENTAL RESULTS

Raw dataset is collected from wafer.netlify.com. Fig. 2 and Fig. 3 represent the process of calibration and recording the data. First need to calibrate then it will start to record the data as shown in Fig. 2 with eight-point calibration where the user will be asked to look at the eight points on the corner of the web page.

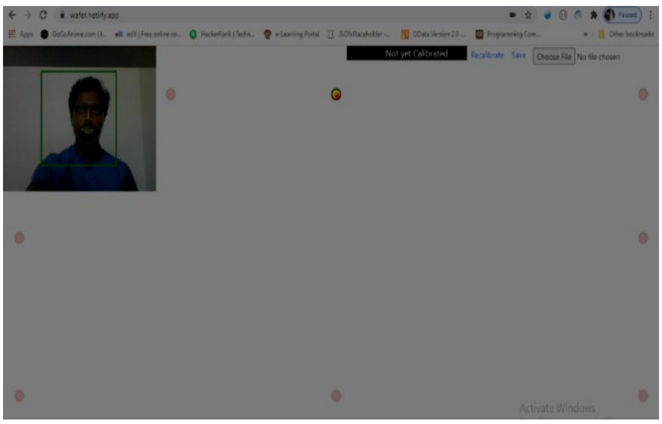

Fig. 2. Callibration before tracking eye movement on webpage

Fig. 3 represents the gaze points where the users have been looking into on the web page. Experiment was conducted on two datasets where; Dataset 1 is labeled with the help of machine learning algorithm and Dataset 2 is labeled by the manual identification using IDT algorithm. Dataset 1 contains total 1075 observations, which are collected from the Web Gazer website (wafer.netflify.com). In the Web Gazer website there will be a 9 red blur dots (Fig. 2) and if we clicked on each dot 5 times then red dot will turn to yellow color (Fig. 3) after that participant should look at the center plot for 5 seconds. Then it will calibrate our eye movement after which we record the data.

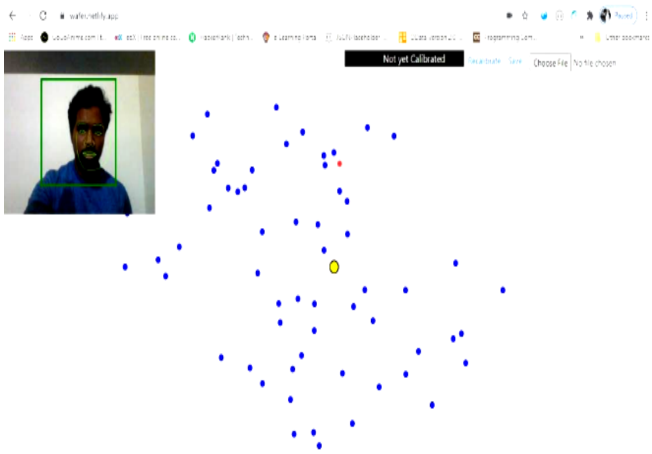

Fig. 3. Gaze points after tracking eye movement on webpage

As it is a raw dataset for that dataset, we have applied I-DT algorithm to identify the metrics. Here the 1075 values are basically divided into two classes which describe the similar metrics captured by the Web Gazer website. The details of each classes and the number of each classes is represented in Table 1 to calculate the efficiency of system which we are using Accuracy, Precession, Recall and F-measures. We used confusion matrix to calculate the accuracy of the system. We conducted three sets of experiments during the experimentation; in which each set contains three different trails. We used 40 percent for training in the first set of experiments and 60 per cent for testing purposes. We used 50 percent for training for the second set of experimentation, and remaining 50 percent for testing. We used 60 percent for training for third set and 40 percent for testing remaining. Each series of tests comprises three distinct trials. Documents are shuffled between training set and test set in each trail.

We have used eye data to calculate the precision, recall, accuracy and f-measure. For calculate these we used KNN, SVM, decision tree and random forest supervised machine learning algorithm.

TABLE II. TOTAL NUMBER OF OBSERVATIONS IN EACH CLASS DATASET1

Classes	Total observations (out of 1075)
Fixation (0's)	1037
Saccades (1's)	38

Here we considered 0's as fixation and 1's as saccades. Dataset 2 contains total of 49 values of data which is collected from the website called web gazer. Where we collected Dataset 1, but we labeled the data by manual identification which describes machine learning algorithm is better than manual identification. The details of the classes are given in Table 2. To calculate the efficiency of the system we use accuracy, precision, recall and F-measures. To calculate the systemaccuracy, we used confusion matrix.

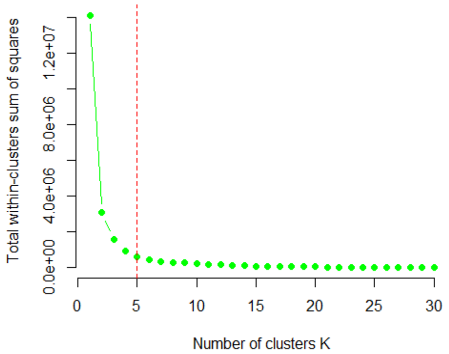

Fig. 4. The representation of Elbow method in K-Means clustering for raw eye tracking data.

Fig. 4 illustrates the process of finding the correct value for k. In K-Means clustering method we have used Elbow method to find K value for the raw eye tracking data. It first finds the sum of square distance within cluster by considering the value for k from 0 to 30. As it is shown in the plot the distance creates an elbow like curve at k=5. After that value the cure almost remains the same. The exact curve in graph showing in the figure is our K value. Through using this K value in the raw eye tracking data, we can classify the fixation and saccades. In our experiment, the K value shows 5. Then group the data into 5 clusters.

TABLE III. TOTAL NUMBER OF OBSERVATIONS IN EACH CLASS DATASET2

Classes	Total observations (out of 49)
Fixation	11
Saccades	20
Smooth pursuit	18

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K-means clustering with 5 clusters of sizes 14, 7, 9, 10, 8

Cluster means:
          X         Y
1 1031.8571  80.78571
2  289.1429 374.14286
3  896.1111 354.55556
4  767.3000 101.40000
5  608.8750 357.50000

Clustering vector:
 [1] 5 5 3 3 3 3 3 3 3 2 2 5 5 3 5 5 2 4 2 2 5 2 2 1 1 3 4 4 5 1 1 1 4 1 1 1 4 4 1 1 1 1 4 1 4 4 1
[48] 4

Within cluster sum of squares by cluster:
[1] 195174.07  78361.71  81657.11  87390.50  96332.88
 (between_SS / total_SS =  87.6 %)

Available components:

[1] "cluster"      "centers"      "totss"        "withinss"     "tot.withinss" "betweenss"
[7] "size"         "iter"         "ifault"
>
```

Fig. 5. K-Means Cluster analysis results

Fig. 5 gives a K-Means cluster analysis for a raw eye tracking dataset. Here it shows the size of each cluster sequentially. And also, it gave a result of a mean value for each clusters and clustering vector. The clustering vector includes cluster only if it is the closer to the centroids. The K-Means algorithm tries to minimize indistinctness, which is defined as the sum of the squares distance of each observation vector in a cluster and a dominating centroid. There is lot of available components in the cluster analysis for example cluster, centers, size etc.

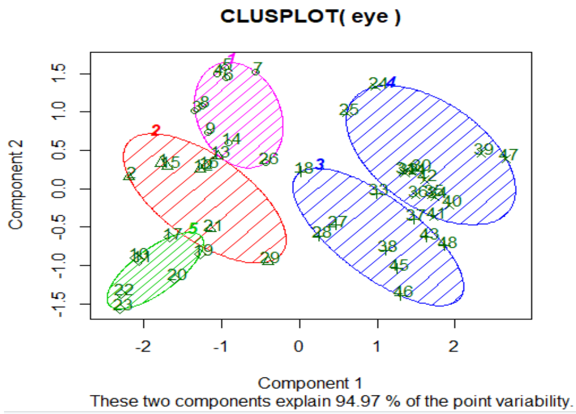

Fig. 6. The K-Means plot of cluster analysis for the raw eye tracking dataset.

The plot in Fig. 6 it clearly shows each cluster. Each cluster represented in different color code. It represents that which data is belongs to which cluster. This cluster is considered as the fixation. Other data can be considered as saccades. For two components X and Y it is showing 94.97% of point variability.

Table 4 represents the detailed experimentation done on both the datasets. The observations in the F measure column represent the actual efficiency of various algorithms used in the proposed method as F measure is a better measure than accuracy. It considers precision and recall both into accuracy which in turn considers both inter class and intra class similarities so that the classification result is not

Method	Data Sets	Testing / Training Ratio											
		Accuracy			Precision			Recall			F-Measure		
		40:60	60:40	50:50	40:60	60:40	50:50	40:60	60:40	50:50	40:60	60:40	50:50
Random forest	[1]	96.74	96.12	96.08	97	96	96	97	100	100	98	98	98
	[2]	60	68.95	66.66	100	83	60	100	83	60	80	83	60
SVM	[1]	96.74	95.96	96.08	97	96	96	100	100	100	98	98	98
	[2]	40	37.93	33.33	0	0	0	0	0	0	0	0	0
Decision tree	[1]	96.97	95.96	96.08	96.97	96	96	100	100	100	98	98	98
	[2]	65	72.41	70.83	65	83	62	33	83	100	50	83	77
KNN	[1]	95.96	95.96	96.08	97	96	96	98	100	100	98	98	98
	[2]	55	62.06	58.33	60	57	71	100	67	100	75	62	83

biased. Dataset 1 performs better as compared to Dataset 2 which falls inline with the low number of observations in Dataset 2 compared to Dataset 1.

TABLE IV. EXPERIMENTATION RESULTS OF VARIOUS ALGORITHMS ON DATASETS

V. CONCLUSION

The machine learning algorithm works well on Dataset 1. We compared four algorithms accuracy and found decision tree and random forest algorithms are the best. In 40 testing and 60 training trails we got highest accuracy for Dataset 1. It shows that the method works well on standard datasets. The Dataset 2 is labeled by manual identification and Dataset 1 is labeled by Machine learning algorithm.

To understand the efficiency of dataset random forest algorithm and decision tree algorithms are suitable. These two algorithms work well on Dataset 1 compare to other algorithms. In 60 testing ratio and 40 training ratio trail we got highest accuracy for Dataset 1 given in Table 4. The proposed method is efficient for the standard dataset and not suitable for the dataset, which are labeled by manual identification. To summarize, random forest and decision tree algorithms are best in order to find eye tracking metrics from raw eye tracking data with a measure of 98%.

VI. FUTURE WORK

The proposed work is a comprehensive study of machine learning algorithms to identify eye tracking metrics, which can be used to develop a free, open source tool to predict eye movements. The findings of the work can be used in the applications specific to eye tracking data without using the paid tool to identify eye movements.

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