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A REVIEW ON DYSLEXIA DETECTION USING EYE MOVEMENT

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ABSTRACT

Dyslexia is a learning disability that impairs one's ability to read, write, and speak. Children with this condition have difficulty connecting the letters they see with the sounds those letters make, but they are often smart and hardworking. The level of trouble of dyslexic children changes from individual to individual [1]. Understanding the pattern of eye movements while the reading process can help distinguish between dyslexic and non-dyslexic people. Features such as fixation and saccadic movements were extracted for the prediction, and then the classification was performed. People with dyslexia have different eye movements compared to [2] normal readers. Dyslexic people have a tendency of having longer fixation and longer reading time as compared to non-dyslexic people. In this review paper, the authors summarized different research dimensions to identify dyslexia.

Keywords: Dyslexia, Support Vector Machine, Random Forest, Xgboost, Dispersion-Threshold Identification Algorithms, Hybrid SVM–PSO, K-Nearest Neighbor, Logistic Regression, Velocity-Threshold Identification Algorithm, Recursive Feature Elimination, Principal Component Analysis, Particle Swarm Optimization.

I. INTRODUCTION

Dyslexia is a type of reading problem where people struggle to read words or letters fluently and are typically poor spellers [3]. Our brains are divided into two halves, the Left hemisphere, and the Right hemisphere. Analytical thoughts, logical reasoning, facts, science, and language are all handled by the left hemisphere. The right hemisphere is responsible for spatial activities such as art, music, intuition, and holistic concepts [4]. According to research, the brains of people with dyslexia depend more on the right hemisphere, the frontal lobe than the brains of people without dyslexia. This suggests that reading causes a longer path through the brain in those with dyslexia and may be delayed in the frontal lobe. It is exceedingly difficult for them to read fluently due to this neurological impairment. As a result, their proficiency in reading and comprehending material is considered quite low. It primarily affects children between the ages of 9 and 13.

Dyslexia can be recognized from the contrast in the person's eye movements while reading [5]. Dyslexia is not a visual impairment, although dyslexic's eye movement patterns are disturbed due to language processing issues. Understanding the pattern of eye movements throughout the reading process can help in distinguishing between dyslexic and non-dyslexic individuals [6] [7]. For the [8] prediction, features such as fixation and saccadic movements were extracted. A fixation [9] is a time during which the visual sight remains fixed on a certain area. On the other hand, a saccade is a quick eye movement between two fixations. Tracking and analyzing fixational and saccadic eye events with machine learning techniques predict whether a child is suffering from dyslexia or not.

II. RELATED WORK

Dyslexia is a learning disorder that affects the ability to read, write and speak, they have difficulty connecting the letters they see with the sounds those letters make. Disruptive eye movement allows us to detect dyslexics using eye-tracking approaches. In this paper, different algorithms and methodologies used by different researchers are compared and analyzed here.

A. Prediction of Dyslexia from Eye Movements Using Machine Learning [2019]

This research work [10] creates a predictive model for dyslexics [11]. Eye movements were captured using Ober-2, a wearable corneal reflection infrared-based eye gaze tracking technology. The eye tracker was used to track [12] the position of the eyes throughout a time interval measured in milliseconds (t). Both eye's

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horizontal (Lx and Rx) [12] and vertical (Ly and Ry) locations were noted. The individuals have to wear infrared goggle, which has four rows of infrared transmitters while being recorded [13]. The distance for viewing was about 45 cm. The left eye moved horizontally first, then the right, and the same for vertical motions. The subjects were instructed to read a text [12] passage that is suitable to their age and their eye movements were tracked while reading. Three questions have to be answered after reading the passage to assess their reading comprehension skills. The dataset contains raw recording data of 185 subjects of age 9 to 10, 97 were dyslexic and 88 were non-dyslexic.

The data are preprocessed to substitute zeros for null values, null values are blanks and shouldn't be considered for feature extraction and classification. The raw eye-tracking data is analyzed to produce a set of derived features. Using statistical measures different types of events such as fixation duration and saccades both progressive and regressive were extracted from the raw data. The feature selection process uses Principal Component Analysis (PCA). Particle swarm optimization (PSO) [14] is used to get optimal weight for features [15]. To get an optimized hybrid kernel, PSO-optimized weight is applied to linear and quadratic kernels. The optimized kernel is used to create a dyslexia classification model. The proposed model uses an optimized kernel function which can be used for SVM classification. The PSO algorithm does kernel optimization. Particle Swarm Optimization (PSO)-based Hybrid Kernel SVM-PSO is used for dyslexia prediction [12]. Fig.1 represents the proposed system architecture. The proposed model has 95% prediction accuracy.

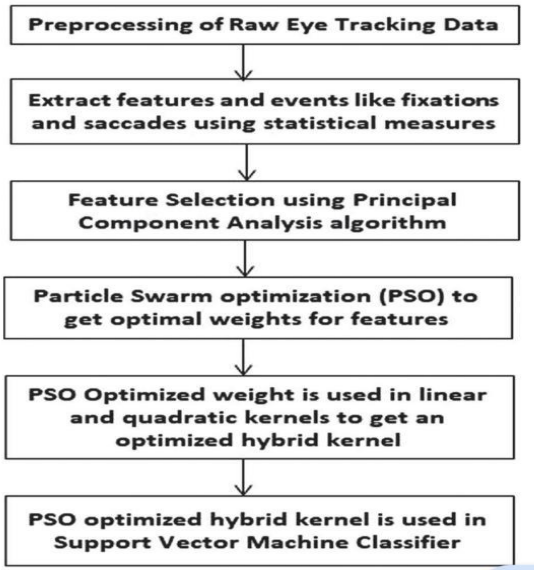

Fig. 1. Proposed system architecture

B. Predictive Model for Dyslexia from Eye Fixation Events [2019]

The goal of this research paper [16] [17] is to come up with a machine learning model for detecting dyslexia from eye movement reading patterns. The idea presented in this research is to create a machine-learning model for the classification of dyslexia using the eye movements [17] and features extracted from the raw eye tracking data [17] using statistical measures. An eye gaze tracker Ober-2 is used for capturing eye movements. The dataset contains raw recording data of 185 subjects studying in the 2nd grade, 97 were dyslexic and 88 were non-dyslexic [17]. The recorded data has five readings Lx, Ly, Rx, Ry, t. x and y denote the eye coordinates. Left eye's x position is Lx, left eye's y position is Ly. The right eye's x position is Rx, the right eye's y position is Ry and t is the time taken for reading in seconds. The data value will be set to zero when the subjects blink. In this paper, Recursive Feature Elimination (RFE) and cross-validated selection of best features is experimented. This approach recursively removes irrelevant or redundant features. Statistical measures were used to extract the set of features related to fixation events from the raw data. A fixation state occurs when the user gazes continuously at a point for a minimum of 80 milliseconds. Both the horizontal and vertical fixation-related parameters need to be measured for both eyes. This study identifies a group of fixation-related eye features which can be used to create a dyslexia prediction model [17]. Fixations are crucial in the dyslexia prediction process. Raw eye-tracking data was used to generate features relating to fixations. Support Vector Machine,

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Random Forest Classifier, and K-Nearest Neighbour were used to train the classification model. The results show that in comparison to Support Vector Machine and Random Forest, the K-Nearest Neighbour Model used in this work achieved a higher level of accuracy of 95%.

C. Predictive Model for Dyslexia from Fixations and Saccadic Eye Movement Events [2020]

In this research paper [18] a small set of eye movement features have been proposed that helps to distinguish between dyslexics and non-dyslexics by machine learning models [2]. To record eye movements, Ober-2, an infrared-based eye tracking device, was used. The reading time (t) in milliseconds (t) was recorded [19]. Horizontal and vertical binocular eye movements were recorded (Lx, Ly, Rx, Ry). The dataset contains the eye movements of 185 children aged 9 to 10 years [19]. Among them, 88 were non-dyslexics and 97 were dyslexics. The proposed Classification model for the Prediction of Dyslexia has four stages. Stage I for preprocessing of raw eye-tracking data, Stage II for feature generation from eye movements using dispersion, velocity, and statistical measures, Stage III for feature Selection, and Stage IV for the classification of dyslexics from non-dyslexics using machine learning algorithms [19].

Preprocessing is necessary to handle missing and redundant data from the dataset. Data that is redundant or missing may produce biased results and contribute to lower predictive accuracy. To increase prediction accuracy, missing values are replaced with the most common values for that attribute. Features such as fixations and saccades [20] are recognized with their spatial characteristics. In this paper, fixations and saccades are identified by using statistical features, dispersion-based and velocity-based algorithms [19]. When compared to using the entire set of features for the same algorithm, feature selection helps us to select a set of features from a larger set of features, improving classification accuracy. It reduces overfitting and allows machine learning algorithms to train faster. Principal Component Analysis (PCA), a feature selection algorithm, is used in this research work to provide transformed features in orthogonal space that can be used as input features for classification. For feature selection, recursive feature elimination with Logistic Regression (RFE-LR) and Support Vector Machine (RFE-SVM) are used. The features selected by using Logistic RFE, SVM-RFE, and the principal components provided by PCA are used to construct an efficient machine learning classification model for dyslexia prediction [19]. Classification of dyslexics from non-dyslexics is done by using a Hybrid Kernel SVM-PSO classifier, Logistic Regression (LR), K -Nearest Neighbor (KNN), Support Vector Machine (SVM), and Random Forest Classifier (RFC) [2]. Fig.2 represents the proposed classification model.

The accuracy of Hybrid kernel SVM-PSO is 95.6%. Logistic Regression [19] gave the highest accuracy of 94.5% like Hybrid kernel SVM-PSO. K-Nearest Neighbor has given good predictive accuracy of 94%. Support Vector Machine (SVM) has 94% accuracy. Random Forest [21] has given good predictive accuracy of 94.5%. Compared to existing ML models, hybrid Kernel SVM with the PSO classification model gave better accuracy.

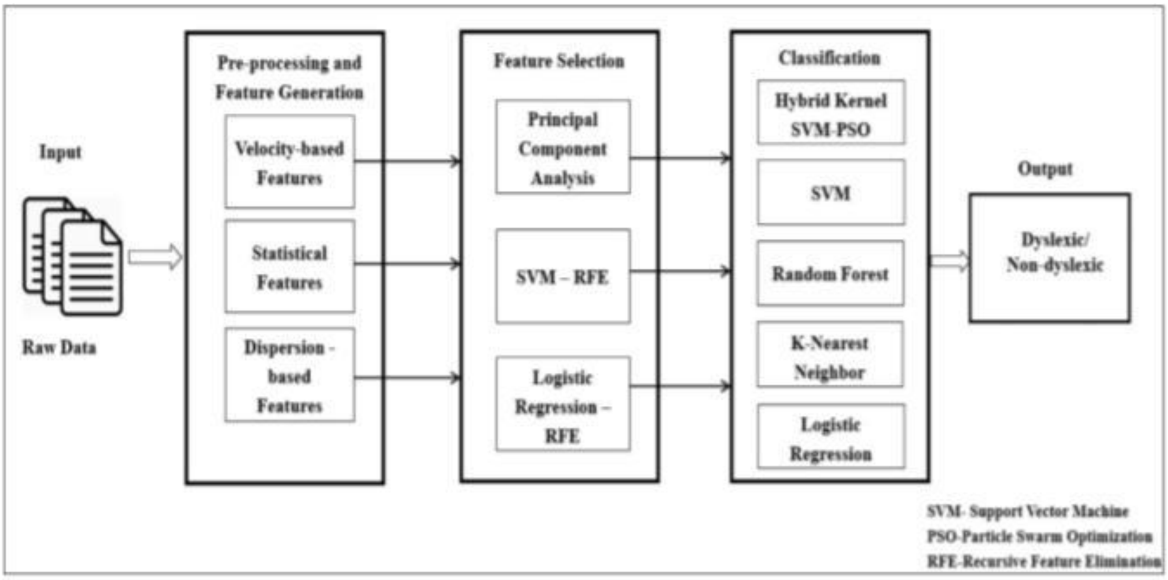

Fig. 2. Proposed Classification model

D. Eye Movement Interpretation for Detecting Dyslexia Using Machine Learning Techniques [2023]

The goal [22] of this paper [23] is to develop a predictive model for dyslexia, using eye movements as the raw data. Here, figshare is used to collect the raw eye-tracking data [24]. It contains [25] a recording of 185 student's eye movements from both the high-risk and low-risk groups [26]. The horizontal and vertical eye movements of both eyes are recorded over a period of time. The subject's eye movements were monitored using an Ober-2 infrared eye-tracking goggle. Each participant was instructed to read a text paragraph while their eye movements were monitored and recorded. Every participant's eye movement was recorded along the x and y axes. When the participants were instructed to read a paragraph to capture the data during the event, the horizontal eye movements of the left eye(LX) were followed by the horizontal eye movements of the right eye(RX). Likewise, the left eye's vertical eye movement (LY) was followed by the right eye's vertical eye movement (RY). After the reading, a few questions were asked to assess the participant's comprehension and understanding skills.

In this experiment, it is also critical to include null values because when participants blink, the focus of the eye moves outside of the screen boundary, and the horizontal and vertical values of the eyes are assigned as null. And during feature extraction, these null or missing values are replaced with zero. The students whose performance was lower than average, faced difficulty in reading, decoding and understanding letters and words were grouped under the high risk (HR) group. Students with above average performance were assigned to the low risk (LR) group. Tracking eye movements while reading has the ability to provide sufficient information about reading difficulties such as dyslexia, the patterns generated by eye movements when reading by a non-dyslexic individual differ from those formed by a dyslexic one. Based on the previous analysis, that was performed on raw data essential eye movement features were extracted. Then, using these extracted features as input, a classification model was trained to determine whether a student is in the high-risk or low-risk group. Fixation and saccades from the eye movements are the main features that are derived using statistical methods. The dynamic dispersion threshold algorithm which is a velocity based algorithm is used to identify fixations in raw data. When the velocity of an eye movement exceeds a specified threshold it is defined as saccades, the space between two saccades is referred to as a blink or fixation. The classification model is trained using the features that were extracted. Support Vector Machine Model, Random Forest Model, and XGBoost Model [27] are the classification models, and these methods are used for detecting dyslexia. Fig.3 represents the proposed model for dyslexia identification.

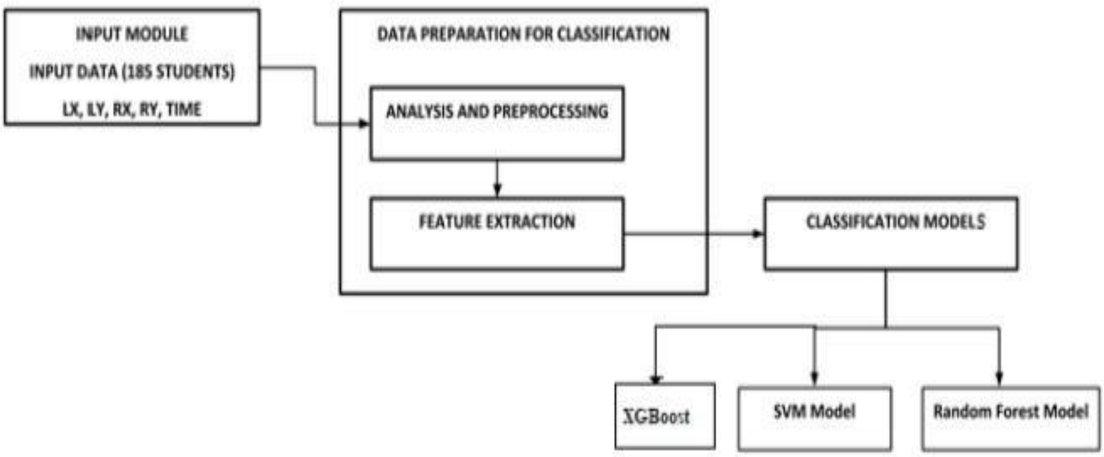

Fig. 3. Proposed model for the identification

SVM Classification Model is used when the number of extracted features is more than the actual data in the data set. SVM classification model was trained to predict whether a student belongs to high risk [HR] Group or low risk [LR] Group. The F1 score of SVM is 94%. The Random forest is used to model complex and intricate behaviors and in this case, student's eye movements are identified and classified them to the risk group they belong to. The F1 score of RF is 90%. XGBoost can deal with missing data by simply avoiding it during pre-processing. The F1 score of XGBoost is 95%.

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III. COMPARATIVE STUDY

Dyslexia is a learning disorder [2] that most often occurs in children in early childhood. Children with dyslexia have difficulty reading, writing and spelling words, despite having average or above average intelligence [2]. Compared to typical readers, dyslexic readers exhibit completely different eye movement behavior. They have significantly longer fixations and shorter saccade durations than typical readers. The dataset of all four papers consisted of raw recording data of 185 subjects, 97 of whom were dyslexic and 88 of whom were not.

In the first publication, PSO-based Hybrid Kernel SVM approach proposed to build a prediction model to predict dyslexia in individuals using their eye movements. To record eye movements, Ober-2, an infrared-based eye tracking device, was used. The goal of this model is to screen subjects for dyslexia in a simple and easy way. The dataset contains raw recording data of 185 subjects of age 9 to 10. PCA [28] is used to identify key features to increase predicting accuracy. Particle swarm optimization is used to get optimal weight for features. An optimized kernel is used to create a dyslexia classification model. The proposed Hybrid Kernel SVM-PSO model is validated on 187 subjects in this study by tracking their eye movements while reading and it achieved 95% prediction accuracy.

In the first paper, the authors used Hybrid kernel SVM PSO model for the detection of dyslexia and achieved 95% accuracy. But in the second paper, RF, SVM and KNN are used. SVM is also used in the third and fourth publications for the prediction of dyslexia. In the second paper, a group of fixation-related eye features that can be used to create a dyslexia prediction model. An eye gaze tracker Ober-2, is used for capturing eye movements. The dataset contains raw recording data of 185 subjects studying in the 2nd grade. Fixations are crucial in the dyslexia prediction process. In this study, fixation-related features were extracted from the raw eye tracking data [29]. Recursive Feature Elimination (RFE) and cross validated selection of best features is experimented. This approach recursively removes the redundant or irrelevant features. Statistical measures were used to extract the set of features related to fixation events from the raw data. The authors [30] tested different algorithms such as RF, SVM, KNN with different features derived from the eye fixation [31] to develop a better predictive model for dyslexia and KNN achieved the highest accuracy of 95%.

In the third study, the authors used different methods compared to the first and second papers. First and second publications achieved 95% accuracy. In the third study, a small set of eye movement features have been proposed that [2] helps to distinguish between dyslexics and non-dyslexics by machine learning models [2]. To record eye movements, an infrared-based eye tracking device Ober-2 was used. Features related to eye movement events such as fixations and saccades are [32] detected using statistical measures, dispersion based and velocity-based algorithms. For feature selection, Support Vector Machine (RFE-SVM) and recursive feature elimination with Logistic Regression (RFE-LR) are used. The features selected by using SVM-RFE, Logistic RFE and the principal components provided by PCA are used to construct an efficient machine learning classification model for dyslexia prediction. Hybrid Kernel SVM-PSO classifier, Logistic Regression (LR), K - Nearest Neighbor (KNN), Support Vector Machine (SVM) and Random Forest Classifier (RFC) [2] are used for classification of dyslexics from non-dyslexics. The accuracy of Hybrid kernel SVM-PSO is 95.6%, Logistic Regression is 94.5%, KNearest Neighbor [14] is 94% and Support Vector Machine (SVM) [14] has 94% accuracy.

Different methods are used in the fourth paper as compared to the first, second and third papers. In the fourth paper, figshare is used to collect the raw eye tracking data and contains a recording of 185 student's eye movements from both the high-risk and low-risk groups. Several types of features such as fixation and saccades were derived using statistical methods. The dynamic dispersion threshold algorithm which is a velocity-based algorithm is used to find fixations in raw data. The extracted features are used to train the classification model. Random Forest Model, Support Vector Machine Model [29] and XGBoost Model are the classification models and these methods are used for detecting dyslexia. The accuracy of SVM is 94%, RF is 90% and XGBoost is 95%.

IV. CONCLUSION

Dyslexia is one of the most frequent and hidden learning disabilities in people, particularly in children. This particularly affects reading, where readers with disabilities take longer to read and understand concepts than non-disabled readers. Understanding the pattern of eye movements throughout the reading process can help

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distinguish dyslexics [33] from non dyslexics. Features such as fixation and saccadic movements [34] were extracted from the eye movements of dyslexic and non dyslexic [33] individuals. Machine learning models are used to detect [34] and classify the individuals with and without dyslexia. The dataset of all four papers consisted of raw recording data of 185 subjects, 97 were dyslexic and 88 were non-dyslexic. In the first paper, Hybrid Kernel SVM-PSO is used for the prediction of dyslexia and accuracy is 95%. RF, SVM and KNN are the approaches used in the second study. The KNN approach is proven to perform better than the other methods by providing 95% accuracy. The third paper employs machine learning techniques; Hybrid Kernel SVM-PSO classifier, Logistic Regression (LR), K -Nearest Neighbor (KNN), Support Vector Machine (SVM) and Random Forest Classifier (RFC) and the [2] accuracy of Hybrid kernel SVM-PSO is 95.6%, Logistic Regression is 94.5%, K-Nearest Neighbor is 94% and SVM is 94%. In the fourth study Random Forest Model, Support Vector Machine Model and XGBoost Model are used for the prediction of dyslexia. The accuracy of SVM is 94%, RF is 90% and XGBoost is 95%. In the future, multiple features can be extracted and can be applied to identify other disorders such as depression, autism, schizophrenia, ADHD.

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