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Machine Learning for Developmental Screening based on Facial Expressions and Health Parameters

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Abstract: The screening tools used by developmental therapists to diagnose sensory processing disorders are primarily manual and based on a static questionnaire. These screening sessions are prohibitively expensive for most parents and there are also no clear scoring criteria. Trained and experienced doctors are needed to examine and treat these youngsters. Early detection and treatment are critically required. Researchers and scientists struggled to model a child's sensory processing pattern. Modern technology makes it feasible to automatically record characteristics related to sensory processing, behavioural factors, and reactions to specific stimuli. A novel dataset is created using smartwatch sensor data and their facial expression as a response to stimuli and a simplified questionnaire. Real-time stress-related health metrics are gathered in response to stimuli. Using the suggested dataset, multiple machine learning models are trained, tested, and validated for the diagnosis of visual sensory processing disorders. With the use of these classification models, behavioral therapists will be able to detect visual sensory processing abnormalities and monitor the efficacy of treatment with less time, reduced effort, and few screening sessions. The experimentation of the proposed system is performed on the novel dataset. The performance of machine learning methods is evaluated using f1-score and standard deviation. The experimentation ensued with promising results. The framework is tested on the live dataset. The experimental results show that the proposed system outperforms the manual method of sensory processing disorder diagnosis by obtaining maximum f1-score of 1 and minimum standard deviation of 0 for decision tree and random forest classifier.

Keywords: autism, sensory processing disorder, machine learning, ASD, technology, screening, deep learning, sensory profile

1. INTRODUCTION

Child development is monitored with the help of various available screening tools. For the purpose of tracking the growth of kids with common developmental problems like Autism Spectrum Disorder (ASD) and Sensory Processing Disorder (SPD), routine screening is crucial. Many ASD children face sensory processing issues. Standard questionnaires are used as screening tools to identify individuals with ASD and SPD and to monitor their development. Because many of the symptoms are similar to those of other diseases and as children grow at a faster pace, timely detection and therapy of SPD is necessary.

Autism is a developmental condition that can be diagnosed in the first few years of childhood and persists throughout life, also known as ASD. Time is crucial for children with ASD. The earlier these children get services, they will be able to get better health outcomes. Early intervention reduces the likelihood that developmental deficits may become irreversible. SPD is characterized by the brain's preoccupation with absorbing and responding to sensory stimuli. For this the evaluation of sensory processing patterns is necessary. But the current process of using questionnaires and observations may occasionally result in human mistakes. This is because human physical regulation does not occur at the same moment each time it is recognized. The health ministry has emphasized the need for early detection, screening, and intervention. One of the diagnostic techniques, a questionnaire, also makes it difficult to diagnose the condition due to lack of clear scoring criteria. [1][2]

Most of the screening tools that therapists employ are manual and built on a standardized questionnaire. For most parents, the expense of these several test appointments is prohibitive. Trained and experienced doctors are required for assessment and therapy of these children as the many symptoms are similar to that of other disorders. Parents

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must consistently monitor and record their children's conduct, and they must routinely share this information with the therapists. To relate the factors that determine the correct strategy for therapy, the therapist must have knowledge and experience. The diagnostic methods that are now available are not economical. They take a lot of time.

All clinical trials and intervention studies have been suspended or terminated during pandemic in clinics, at home, and service centers. COVID-19 related restrictions and regulations have limited our study. Suspension of in-person schooling, nonacademic interactions, recreational activities, scientific data collection and normal health services affect the physical and emotional quality of life of children.

As the 2019 coronavirus disease outbreak prevalence keeps rising around the world, persons with ASD are identified as members of a higher-risk group. To help stop the spread of the coronavirus (COVID-19), parents and kids had to stay at home and away from others. It has transformed many of our daily activities. For anyone but particularly for children with developmental disorder who have difficulty with change, adapting to a new routine was stressful. This caused significant emotional and behavioral upheaval. It was more challenging to obtain the required treatments from caregivers, practice physical distancing, and adapt to everyday tasks interrupted. Parents or caregivers should support autistic children, observe and convey their symptoms with the health care provider in order to struggle with the problems and provide significance for the attitudes, needs, and communications of the child during the pandemic. New models of treatment have become increasingly important to overcome gaps in accessing autism-specific diagnostic and intervention services.

The most recent technologies allow for the automatic selection of characteristics linked to behavioral factors and the reaction to certain stimuli. For this, We can utilise face expressions and health metrics gleaned through wearables. This will allow children to lessen the effects of physical and psychological impact of screening on the children. The machine learning algorithms are used to overcome the problems of using screening tools.

Objective of research.

- To detect the audio-visual sensory processing disorder with reduced questionnaires by using automatic features collected with health sensors and facial expressions.
- To reduce the time and efforts by behavioral therapist by using machine learning models for classification

The proposed web application which is designed for the remote detection of sensory processing disorder is useful for the parents and therapists. This will help for regular assessment and therapy with the use of machine learning algorithms in the web applications.

The work is divided into the following sections: Section 2, which summarizes numerous clinical techniques for screening autism and sensory processing disorder. The dataset utilized for the experiment is described in Section 3. The suggested technique to identify auditory and visual SPD is introduced in section 4. Section 5 presents the obtained results. The conclusion, the area of future research, and the different problems and difficulties encountered throughout the study are all summarized in Section 6.

2. RELATED WORK

A recent study shows that children with ASD should receive treatment sooner so that the brain can develop new abilities at a younger age throughout this period. Healthcare providers are recommended to conduct early and frequent screenings. They should also help parents understand the next steps regarding follow-up care. Otherwise ASD can evolve over time. [3] [4] It has been shown that delayed ASD care severely worsens behavioral and cognitive outcomes. ASD diagnostic specialists are rare and have lengthy wait lists. Many services are clustered in urban areas, causing long distances for certain families to drive.[5]

Autistic kids have social interaction challenges, and therefore excel well when engaged in loving, supportive settings that primarily assess their social progress through kindergarten, playgrounds, and counseling sessions. Therefore, because of the basic nature of social exclusion during the COVID-19 pandemic, this became nearly difficult to achieve for someone other than immediate family members. Because of concentration issues or difficulties adapting skills acquired on the computer screen to in-person activities and social environments, many children do not have the ability to interact effectively in a simulated environment. It may be more difficult to re-engage with peers because of the lack of social, behavioral and speech learning and applying that happened during this time. [6] [7]

It is not a desirable assumption to shift the burden for therapy solely to parents, especially those with limited resources and lack of experience who are likely to face greater barriers to therapy involvement. Parents have to devote more time watching the actions of the child, when caregivers might not be present. Also, the teachers might not be able to assess the child's progress effectively which is helpful in deciding the direction of the behavioral therapy. This deepens the difference in growth between those with available resources and those without. These resources are knowledge to assess behavior, strong communication skills, computer, internet connection, time and financial stability.

A quick examination called developmental screening can determine if youngsters are picking up fundamental abilities when they should be or whether there may be delays. During an evaluation to determine how the kid learns, talks, acts, and moves, the behavioral therapist may ask the parent some questions or converse and play with the child. It's critical that doctors check all kids for developmental problems.

Sensory processing disorder diagnosis is based on sensory profile which also helps to discriminate against a group of children based on the sensory responses and behaviors. This diagnosis is based on the frequency, intensity and patterns of behavior. To complete the sensory profile, several questions are posed to kids, and behavioural observations

are made. One or more sessions can be used to complete this. The sensory profile is used to emphasise the influence of the sensory system on functional performance and to examine the child's sensory processing pattern in normal surroundings during diagnostic and treatment planning. The diagnosis of SPD is based on a sensory profile, which also aids in the differentiation of children into groups based on sensory reactions and behaviors. This diagnosis is based on the frequency, severity, and patterns of the behavior.

Lower SOR score indicates more SSP issues and more sensory over-responsivity. Therapists employ various techniques to increase positive or decrease negative behavior, and constantly collect data on success and failure. Screening tools help for this evaluation also. That way it is clear whether the child is making progress. If not, the therapists can adjust their approach. [2] [8]

The aim of Multi-Sensory Environments (MSEs) is to promote the growth of the reasoning and intellect. Due to a shortage of people and services, advanced economies, however, use an empirical approach when developing intervention programmes for children with disabilities in MSEs. It is possible to use an expert system to automatically assess which recovery programs for children with disabilities are suitable. The expert system can be designed using a model based on decision trees to suggest a therapy plan selecting pairs activity-module.[9]

Primary tools that are useful for tracking autistic individuals, such as wearable devices, communication protocols and data processing techniques.[10] The health monitoring system can be developed using much superior and powerful sensors and accurate algorithms like SVM, CNN and other deep learning models. [11]

A dynamic anxiety detection model has been created by Bastos et al. with the use of an enhanced Artificial Neural Network (ANN). The input EEG signal from the database was first pre-processed using a Band Pass Filter to remove noise and artefacts from the signal, and then the relevant characteristics were selected to reduce complexity. The suggested Trace and Forage optimization (TF) technique, which was developed by combining the traits of rescue search agents and Finches to acquire the better capacity of detection, was used to train the ANN, which is then used for the detection of anxiety.[12]

For automated behaviour evaluation in 2020, Brass et al. offered Child-Robot Interaction (CRI) and technologically based methodologies. Robot-assisted tools that make use of CRI concepts have been discovered to indicate quicker intervention for kids with ASD when compared to conventional methods. Additionally, employing automated video coding to summarise the replies and computer vision to assess children's behaviour might assist physicians in shortening the time it takes to diagnose ASD. The use of conventional diagnostic methods for ASDs has been suggested to increase feasibility. For automatic face analysis, the system uses machine learning and the Robot Operating System (ROS). [13]

The summary of the literature is given in the Table I

The research gaps are identified as follows:

1. In India, manual evaluation tools that are based on a static questionnaire are most commonly utilized by developmental therapists.
2. There is no literature on automatically detecting SPD.
3. It still takes time and is prone to error to calculate a child's sensory profile score to see if they have SPD.
4. Identification of features related to SPD detection is necessary.
5. There is no dataset currently available for SPD detection, and there is no ML classification method for SPD detection

3. DATA

Smart watches have a number of internal sensors, such as a heart rate monitor and a thermometer, which can provide helpful information for analyzing child behavior patterns and gathering health-related screening data. This information is then transmitted to a remote server for offline and real-time analysis. The heart rate sensor, as its name implies, counts the beats that our heart makes. This sensor monitors it by checking our pulse on a regular basis.

Smart phone cameras can capture very good quality videos now-a-days. A high-resolution mobile phone camera was used to record videos of facial expressions. The probability mass function was used to construct the emotion data after the facial expressions were retrieved. The parameters were recorded using a web application. Based on their regular behavior observations, parents complete the condensed questionnaire. Seven days were spent conducting the experiment. 15 kids between the ages of 5 and 14 were exposed to the visual stimuli designed by the experts, and their facial video and health metrics were recorded. From video taken while being exposed to represented stimuli, the probability mass function (PMF) for seven facial expressions—angry, disgusted, scared, happy, neutral, sad, and surprised—is extracted. The experimental setup for data collection is summarized in Table II

The stimuli are portrayed to the children. Stimuli are positive and negative based on the expected set of emotions as their response. The smart watch measures body temperature and heart rate. From video collected during depicted stimuli, the probability mass function (PMF) for seven facial expressions (Angry, Disgust, Fear, Happy, Neutral, Sad, Surprise) is derived. Parents fill out a simplified questionnaire based on their observations. The data is saved in csv files. Thus, as a response to particular stimuli, facial expressions are captured with a camera and heart rate and body temperature are captured with the smart watch. Web Application is used to upload the parameters captured during the screening. For this web application, we have used Software tools: Python flask, HTML, CSS, SQLITE.

Steps for using the web application to create the dataset:

1. Sign in if a new user and set username and password. Move to step2.

TABLE I. Summary of literature

No.	Author Name	Technique used	Work done	Performance
1	Philip Schmidt, Attila Reiss, Robert Duerichen, Claus Marberger Kristof Van Laerhoven , 2018 [14]	Created stress related dataset based on chest body temperature, blood volume pulse (BVP), electrodermal activity (EDA)	The data has been recorded using two different devices (one chest-based and one wrist-based), physiological and motion modalities	80% accuracy for 3-class classification - baseline vs stress vs amusement and 93% accuracy for 2-class classification -stress vs. non-stress
2	Russell Li and Zhandong Liu, 2020 [15]	Created stress related dataset based on chest worn and wrist worn sensors- ECG , EDA, EMG, skin temperature respiratory rate sensor, and 3-axis accelerometer and BVP, electrodermal activity ACC	Used random forest algorithm	UAccuracy for wrist parameters and random forest: 87.1% Accuracy for chest parameters and random forest: 92.87%
3	S.Dedgaonkar, R.Sachdeo, and S.Godbole, 2021 [16]	Using a novel feature vector with reduced questions , PMF for emotional stimuli, body temperature, heart rate parameters and machine learning, SPD was conducted	SPD detection is automated	SPD detection DNN accuracy:96%

TABLE II. Data collection experimentation

No.	Requirement	Particulars
1	A Web Application	Webapp created for data feeding
2	Smart Phone Camera	13 MP Rear Camera (1080p)
3	Smart Watch Sensors	PPG Heart Rate Sensor
4	LCD display	To portray stimuli
5	Smart phone	Vivo Y15 S With Android Version 12
6	Smart watch	Mi Smart Band 5
7	Samples	Child with age 5 to 14
8	Location for experiment	Developmental Screening Room At Child Clinic

2. Login to the system.
3. Enter the age of the child and give the rating (1-some times to 5-always) for the simple questions set by the expert for detecting sensory processing disorder.
4. Portray the positive / negative stimuli designed by experts related to sensory processing.
- During the screening session, record a video of your face and upload it.
- Measure the temperature and heart rate during the screening session and upload this value.
5. Submit the data and get the report.
The report is generated by applying the classification model trained using artificial neural network algorithms. The output can be- Typical, over-sensitive or under-sensitive child.

4. Proposed system

Monitoring of body parameters using sensors and facial expression recognition as a reaction of audio and visual stimuli will help to recognize the sensory disorders using machine learning. This will speed up the disorder detection process and decide the appropriate therapy. Also, the results of the therapy can be tracked easily. This will reduce the efforts of therapists, parents and caretakers for identifying the features by constant monitoring. The

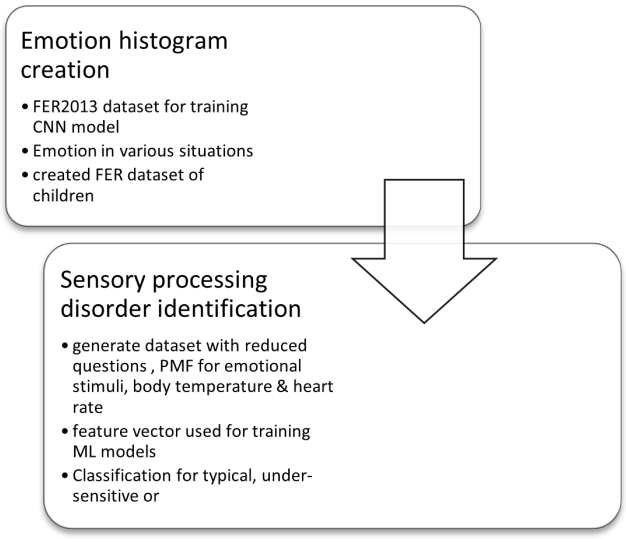

Figure 1. Research stages

research stages followed are shown in the Figure 1.

As shown in the Figure 2 , in the suggested approach, children are shown stimuli in order to gauge their reactions to the same. By taking into account the questions in Winnie Dunn's sensory profile and collaborating with behavioral therapists, we have produced audio and visual stimuli. Loud noises like sirens, hair dryers, automobile engines, and dog barking make up the stimulus. Strange noises like the tuning of a radio, a refrigerator, and a vacuum or hoover are also present. An autistic patient could be sensitive to or respond strangely to these everyday noises, which come in a variety of frequencies and pitches. [16]

Pictures with very dark backgrounds, vivid images, and images with green and red hues make up the visual stimuli gathered. These photographs are a collection of many crisp and bright hues since many autism patients are stimulated by such colours or images or are unable to view the colours or images as normally as individuals.

The child's health characteristics are measured at the precise moment when he responds to stimuli using a combination of wearable sensors. When an autistic person is exposed to various stimuli, their body temperature and heart rate are continuously monitored in order to track any changes in these parameters.

Deep learning has a strong potential for automated recognition, the authors [17] focused on using it to identify facial expressions of emotion. In this context, they demonstrate the proposed deep learning techniques to get superior detection. Several static or sequential databases can be used to practice on. For FER across many accessible datasets, deep CNN is employed. The images were downsized to 48x48 pixels after the face landmarks were extracted from the data. Once that was done, they used the augmentation data approach. They noted that CNN exhibits improving local performance as a result of locally applied convolution layers, and that this method also makes it feasible to lessen the over-fitting issue. The goal of a support vector machine is to identify the hyperplane that minimises the distance between the support vectors and the hyperplane. In other words, the algorithm creates an ideal hyperplane that classifies incoming cases based on labelled training data. When just a small number of training samples are available, SVMs have demonstrated great result for identifying highly dimensional data.

By employing several layers, often more than seven layers, deep learning is utilised to accelerate the neural network's learning process. Convolution Neural Network is a deep learning model that is frequently utilised for image categorization (CNN). In the widely used Artificial Neural Network (ANN) technique for image recognition, CNN is one of the variation models. The CNN immediately detects several high-level characteristics in the raw input. [18] its name suggests, CNN makes use of the convolutional algorithm. by adding a convolution filter of a specific size to a picture. When it came to classifying objects in photos, the CNN method excelled other Machine Learning techniques.

An open-source machine learning platform is called TensorFlow. Its extensive ecosystem, libraries, and community may aid academics in creating cutting-edge machine learning technologies and make it simpler for developers to incorporate machine learning into their applications. The Keras API specification is implemented by TensorFlow using the Keras library. TensorFlow is made simpler to use with Keras without compromising performance or versatility. Numerous image processing techniques are included in Scikit-Image. Scikit-Image is unrestricted and cost-free to use.

The processing of the dataset is done using the following steps.

1. Extract faces from captured screening video using Haar cascade classifier.
2. CNN is used for emotion classification and identification using the filtered FER 2013 dataset. Along with the emotion code, the facial images are included in the dataset. Facial expressions can be classified as Angry, Disgust, Fear, Happy, Sad, Surprise, Neutral.
3. Emotion histogram and PMF generation which are useful for emotion pattern tracking.
4. using health and RSSP data together to create a proposed hybrid feature vector for SPD identification.

The experiment output is created into the following sequence: video frame, face extraction, face detection, FER dataset developed for autistic children, PMF for emotions, and feature vector for sensory processing disorder classification.

Algorithm:

1. Start the screening system: Start audio player, monitor and cameras. Charge the smart watch. All sensors must be kept on and should capture the parameters continuously.

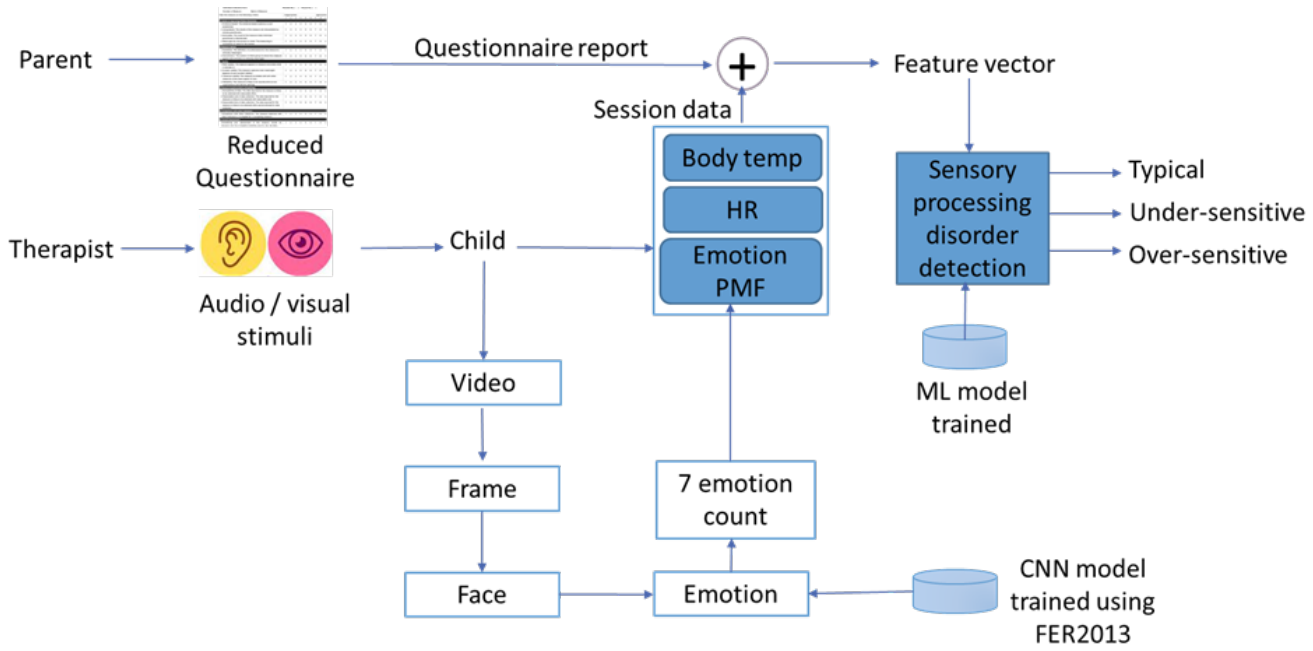

Figure 2. The proposed system

Children should wear smartwatches.
2. Decide whether to predict audio or visual sensory disorder
3. If path 3, predict audio sensory disorder, go to 5.
4. If path 4, predicts visual sensory disorder, go to 6.
5. Play audio stimuli and go to 7.
6. Portray visual stimuli and go to 7.
7. Store the videos captured during screening. Find out the facial frames, classify emotions from the face and store the emotion PMF.
8. Store the heart rate and temperature data captured during the screening session.
9. Clean the data to create a pre-processed database for the feature vector.
10. Apply machine learning/ deep learning algorithms to perform classification and prediction.
11. Predict the disorder level and stop the system.

5. RESULTS

For the purpose of identifying sensory processing disorders, we have suggested an unique hybrid feature vector. Instead of manually calculating scores on the lengthy questionnaire, a significantly smaller number of questionnaires are processed automatically using machine learning.

A. CNN model for emotion recognition

The CNN model for emotion recognition and classification on FER 2013 dataset gave accuracy of 0.86.The confusion matrix obtained seven emotions and 30 epochs is given in Figure 3.

The emotion histograms as shown in Figure 4 identify any obvious differences and patterns in emotions. It will be used to track the development of children.

	Angry	Disgust	Fear	Happy	Sad	Surprise	Neutral
Angry	137	0	1	16	7	4	0
Disgust	10	0	2	5	12	8	4
Fear	10	0	63	11	12	21	6
Happy	4	0	0	656	5	4	0
Neutral	14	0	1	26	463	11	1
Sad	9	0	1	16	4	129	0
Surprise	1	0	10	12	13	1	286

Figure 3. Confusion matrix for CNN model

B. SPD diagnosis

Input dataset: Novel hybrid feature vector
Records: 10313 records for responses to various stimuli
Output: Classification – 0 (Typical), 1 (under-sensitive), 2 (over-sensitive) Decision tree, Random Forest algorithm, ANN, DNN have better accuracy. The performance analysis of the classification models is, as shown in Table III, with f1-score. For imbalance data, f1-score is a more useful metric than accuracy and it combines precision and recall. Precision is a metric of correctly identified SPD class out of all samples classified under that class.

TABLE III. SPD detection result

Algorithm	f1-score	k-fold mean	Std deviation
k-nearest neighbors (k-NN)	0.99	0.93	0.047
Support Vector machine (SVM)	0.95	0.96	0.027
Decision tree (DT)	1.0	1.0	0
Naïve Bias (NB)	0.99	0.99	0.02
Linear discriminant analysis (LDA)	0.95	0.96	0.027
Logistic regression (LR)	0.93	0.86	0.10
Random Forest Classifier (RFC)	1.0	1.00	0
Neural Network (NN)	1.0	0.97	0.017
Deep neural network (DNN)	0.97	-	-

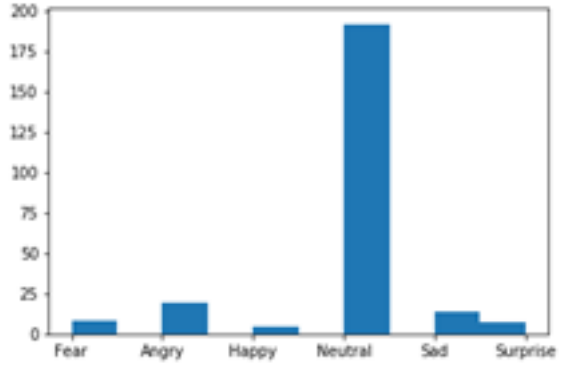

Figure 4. Sample emotion histogram

One method that aids in our model evaluation is k-fold where k=10. The holdout approach is repeated k times using the k-Fold validation procedure, where each of the k subsets is utilized as a test set and the remaining k-1 subsets are used for training. The average error from all of these k trials is then determined, which is a more trustworthy way than the traditional handout method. Even for fewer epochs, the accuracy of K-Fold Averaging is significantly superior than that of the Standard Holdout technique. The final model should be more robust than the standard one in addition to having excellent accuracy.

Figure 5 shows the RoC curve obtained by the ML algorithms. RoC curves predict the tradeoff between the sensitivity and specificity. The experimental results demonstrate that by achieving a maximum f1-score of 1 and a minimal standard deviation of 0 for decision tree and random forest classifier, the proposed system surpasses the manual technique of diagnosing sensory processing impairment.

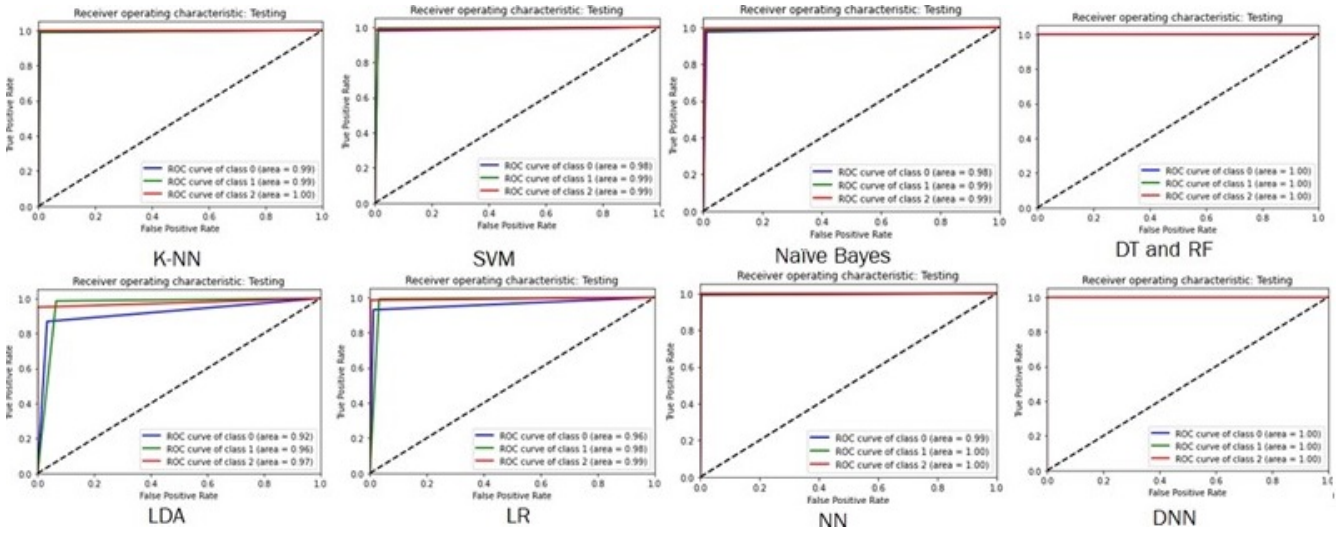

Figure 5. RoC curves for the ML algorithms

6. CONCLUSION

The field of developmental therapy expects the contribution of artificial intelligence in early diagnosis of disorders so as to suggest appropriate therapy. For the purpose of identifying sensory processing disorders, we have suggested an unique hybrid feature vector. Instead of manually calculating scores on the lengthy questionnaire, a significantly smaller number of questionnaires and automatically collected parameters are processed using machine learning. The proposed system has suggested an easy and fast approach for audio and visual sensory processing disorder detection. It needs a smaller number of staff and constant monitoring is possible which is good for the parents, doctors and caretakers. The proposed method identifies unique features associated with the sensory processing of that individual. Automatic parameter collection is done for dataset creation. This type of semi-automatic Sensory Processing Disorder detection system will be used by behavioral therapists. The novel feature of this invention is: this system will use reduced questionnaires along with body parameters and facial expressions. The system will be useful to track the progress of the child and decide further plans of therapy. [19] [20]

Numerous autistic kids object to wearing any attachments, even a pulse oximeter. Therefore, we may gather bodily characteristics using smart watches or fabric sensors. Additionally, we can remotely measure temperature using infrared thermometers. This work is limited to detect auditory and visual sensory processing disorder and can be extended for other types of sensory disorders as well.[21] [22]

It is possible to improve the proposed system by using more health sensors and optimization algorithm. Along with audio visual sensory processing, we can track the development of child with respect to other sensory processing like motor skills, touch senses, oral senses etc. Multiple stimuli can be designed for tracking the behavior for day-to-day activities of the children.

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