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AI Tool for Early-Stage Dementia Detection

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Abstract: ***The fact that dementia causes damage to brain functions and even communication in people cannot be overemphasized. However, the difficulty lies in the fact that the disorder occurs in a very covert manner because the symptoms are gradual and hence difficult to detect at an early stage of the disease. There are no specific tests for diagnosing dementia. In this context, this paper aims to propose a web-based AI-powered tool for early detection of dementia, replacing conventional methods of dementia detection by providing a comprehensive tool for speech analysis and cognitive tests, making it easier and convenient for early detection of dementia. The tool will have the ability to gather data from the user, which will enable the comprehensive analysis of the user's cognitive state by extracting features related to the user's speech. The data collected would be passed through a number of algorithms. This would help in extracting features and classifying the data by making use of the Random Forest, SVM, and Logistic Regression algorithms. The ensemble method will be used to ensure accurate predictions. The tool will have the ability to generate a risk score related to dementia. This will enable the user to be classified according to their risk level. This will ensure that the results are clear to the user, thus enabling them to make the right decisions. The proposed tool will be able to provide a cost-effective, convenient, and non-intrusive tool for early detection of dementia, making it easier for people to consult their doctors, thus improving their health status.***

Keywords: Cognitive Assessment, Dementia Detection, Early Diagnosis, Healthcare AI, Machine Learning, Speech Analysis.

I. INTRODUCTION

Dementia wears away at memory, communication, thinking, and behavior. It slowly takes over and, let's face it, can make life tough for everyone involved. The early diagnosis of dementia is important for ensuring improved health outcomes of patients. Unfortunately, early-stage patients often have issues with their memory and language abilities, which are viewed as part of normal aging, leading to late diagnosis [14]. Current findings indicate that speech and language characteristics can be used as non-invasive markers for dementia detection due to the information they reveal about brain activity [1], [10], [12]. Moreover, tests that examine memory, attention, and reasoning skills play an important role in screening people who might have dementia [9]. Because of the advancements in AI and ML fields, speech and cognitive tests data can be successfully processed and classified without facing any problems. There were numerous studies conducted in the field of speech recognition methods of detecting dementia [6], linguistic features [10], and multimodal systems that combine audio and written information [3], [4]. Speech can be processed with deep learning techniques such as embeddings and neural networks [15]. Moreover, several previous studies have found that the integration of speech recognition and natural language processing techniques can aid in the identification of the early onset of dementia and cognitive impairment [16]. Such methods emphasize the necessity of examining language and speech patterns in order to detect accurately.

However, these innovations do not mean that currently available solutions are applicable in real-life scenarios [7]. Most approaches use only one form of information, which can be auditory or cognitive testing; thus, they cannot efficiently measure a person's full cognitive condition [6], [9]. That is why, an approach that will allow using both speech and cognitive testing at once needs to be developed.

Steps involved in this method include the gathering of data, data processing, feature extraction, and classification through several machine learning techniques. In this approach, the input data is made up of speech information from which different features, including pitch, pauses, and speech rates, are extracted. At the same time, cognitive test results are converted into numerical form. These features are used for classification using various machine learning algorithms like Random Forest, Support Vector Machine (SVM), and Logistic Regression [1], [3]. In addition, an ensemble method is used for classification, which helps increase the accuracy and reliability of the classification model [2], [4].

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II. LITERATURE SURVEY

Z. Jahan et al. [1] The objective of the paper is to detect dementia by developing an early detection system for patients suffering from dementia. The author has used various features for the detection of the disease. SVM and Random Forest have been applied for classification.

M. Ksibi et al. [2] The author has proposed a new method for the detection of the disease by analyzing the speech of the patients. The author has focused on female patients for the proposed system.

H. Lin and S. Washington. [3] The research has proposed a new method for the classification of dementia patients using a multimodal deep learning approach for considering both text and speech for the classification of patients with respect to whether they are suffering from dementia or not.

X. Chi et al. [4] In this work, the authors have proposed a multimodal AI-based approach for predicting cognitive decline by taking into consideration the speech and other metadata for the classification system.

A. Cenacchi et al. [5] In this paper, the authors have proposed analysis of facial micro-dynamics for passive dementia screening. Deep learning is used.

K. Ding et al. [6] The paper discussed various methods for detecting dementia through various features of the speech of patients, such as MFCC and pitch. It also highlighted the importance of combining various features of the speech of patients to achieve accurate results.

F. Tsoi et al. [7] The paper discussed various applications of artificial intelligence for detecting and diagnosing various types of dementia. Also, it highlighted the significance of artificial intelligence during the detection and diagnosis of various types of dementia

R. Li et al. [8] This paper focused on the use of artificial intelligence during the detection and diagnosis of various types of dementia using different types of medical data like MRI scans.

Y. Zhang and S. Ren. [9] This paper explained different techniques used for the detection and diagnosis of various types of dementia through cognitive tests. Also, it emphasized the efficacy of artificial intelligence during the detection and diagnosis of dementia through cognitive tests.

A. Li et al. [10] This paper covered different approaches to the detection and diagnosis of different types of dementia based on features related to speech of individuals and language structures.

S. Martinc et al. [11] The authors presented explainable machine learning techniques, such as XG Boost and Decision Tree, to identify dementia from speech information. The major focus of this paper was on increasing model transparency by using visualization techniques such as SHAP and LIME for feature importance assessment.

S. Luz et al. [12] In this paper, an ADReSSo dataset was proposed for validating dementia detection models through speech data. Speech-related parameters like pauses and fluency proved to be useful for early-stage detection of cognitive impairments.

S. Luz et al. [13] A benchmarking corpus was created in this research for dementia detection with speech information. Multiple machine learning and deep learning techniques were used for analyzing speech patterns.

C. Fraser et al. [14] This research focused on the examination of language components such as coherence, vocabulary, and narrative skills. The algorithms that have been used included the machine learning algorithm known as Random Forest.

A. Haider et al. [15] The paper examined linguistic features using deep learning methods, such as the use of wav2vec embeddings and LSTM models in the analysis of speech data. It is shown how the application of deep embeddings allows for early dementia identification.

J. Alhanai et al. [16] The paper explores techniques of speech recognition and NLP to identify cognitive dysfunction disorders. It demonstrates how the combination of speech and language data analysis can detect early signs of dementia.

III. GAP ANALYSIS

Nevertheless, despite the success achieved in researching dementia diagnostics using artificial intelligence and machine learning, there are some limitations that remain unresolved. Firstly, most studies utilize unimodal methods of data analysis, such as speech recognition [1] or cognitive assessment [9], making it impossible to detect the full spectrum of mental processes experienced by a person. While multimodal data processing yields better results, it is usually complicated and requires large datasets [3], [4].

Secondly, many systems depend highly on medical data such as MRIs or clinical reports [8], which makes them difficult to use in screening procedures for the public. Such algorithms are expensive and hard to access even in underdeveloped regions.

Thirdly, many algorithms remain non-operational due to being developed for research purposes only. They are never used in practice or developed into convenient applications [7].

Moreover, despite being rather accurate, deep learning algorithms may need intensive computations, as well as large amounts of data for training [2], [15].

IV. METHODOLOGY

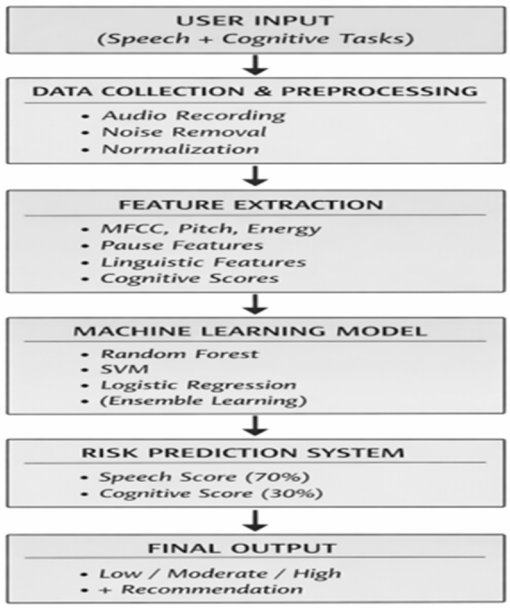


Figure 1: Work Flow

The proposed system will have a workflow for early dementia detection through both speech and cognitive input data. The collected data will be preprocessed to improve its quality and remove noise from the data. The model makes use of the Dementia Bank dataset, which is a commonly utilized dataset for conducting research on dementia. The dataset consists of speech samples along with their corresponding transcripts for healthy individuals and patients suffering from dementia.

A. Data Collection and Preprocessing

The system collects speech data and cognitive test data through a web interface. Preprocessing techniques are used, including noise reduction, normalization, and speech recognition, on the speech data, and cognitive test data are covert into numerical form for analysis.

The system employs Dementia Bank database, which is very common when carrying out research related to dementia. The database contains voice samples as well as transcriptions of both people without dementia and those who have dementia. These sample data are then used to train the machine learning algorithm.

B. Feature Extraction

The system extracts Features from the speech data, pitch, pause, and speech rate, and from the cognitive test data, scores. It provides a comprehensive feature set of the data of the users of the system.

C. Training Models

The model uses machine learning models to train models that include random forest, SVM, and logistic regression algorithm to classify. This enhances the accuracy of the model through better results.

D. Prediction and Risk Scoring

The risk score predictor model will predict the risk score according to the features used for training. Classification of users into two groups; the low-risk group and the high-risk group will be shown alongside suggestions for each group.

Generally, the proposed system integrates both speech and cognition data in one system to help diagnose dementia.

V. SYSTEM ARCHITECTURE

This process will be done using the methodology used in web application development. As per the model, the utilization of the system will happen using the GUI where the user talks while executing his mental activities. This process will be executed at the backend of the system, where data analysis will be performed.

Data preprocessing at the backend of the system includes the extraction of features like pause, pitch, and MFCC from the data.

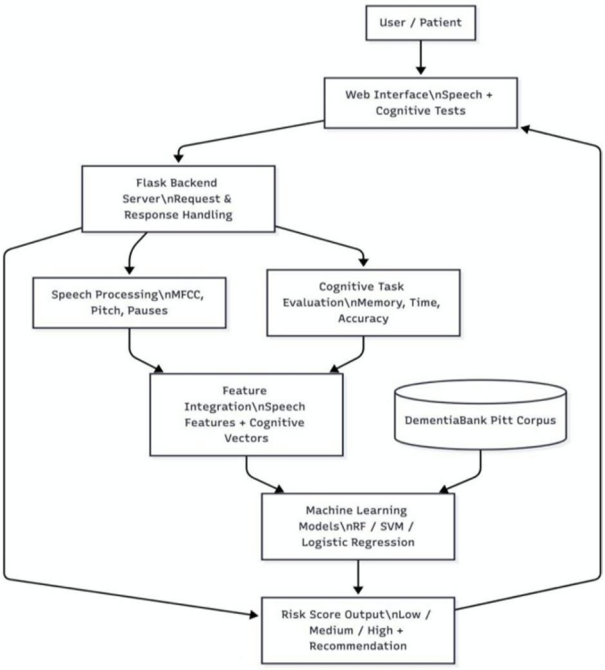


Figure 2: System Architecture

Performance of the user in cognitive activities will be measured by numeric scores. Once the features have been extracted, all the features can be merged together in one feature vector.

By way of example, the proposed framework uses the design methodology of modularization whereby different modules will take care of different tasks. The front-end module takes care of the user's inputs while the back-end module deals with raw data and machine learning algorithms. Random forest, support vector machines, and logistic regression represent the different types of algorithms used in data classification. While carrying out the process of combining features, the speech feature vector and the cognitive feature vector are combined to form the feature vector that forms the input for the machine learning algorithm that uses the dementia bank database.

VI. **IMPLEMENTATION** DETAILS

The suggested methodology could be presented in the shape of a web-based application in order to use it as an interface for early-stage dementia diagnosis. HTML, CSS, and JavaScript have been chosen as a programming language for designing the front-end of the proposed system to make sure it is user-friendly and convenient to use when testing speech and cognitive functions.

Flask framework has been selected as a tool to process data acquired from patients, extract needed characteristics, and interact with machine learning algorithms. Speech samples will be collected using a web browser, and then acoustic analysis will be carried out. Testing of cognitive functions will also be done using the created software.

Machine learning models like Random Forest, SVM, and Logistic Regression will be trained on the Dementia Bank dataset.

VII. RESULT

The outputs generated from the model show that the model can be applied to diagnose patients in the early stages of dementia from the use of their speech and cognitive test scores. This model accepts input data from users and generates a risk score through the use of the features extracted from the user's inputs and the outcome of machine learning models. The outputs generated from the proposed model are presented below in an easily understandable format. Information on the outputs generated from the model is given below.

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A. System Output

The system output provides the computed dementia risk score from the use of the user's inputs. The system provides the risk category of dementia (low/ high) along with the percentage.
Also, it gives the recommendation to the users.

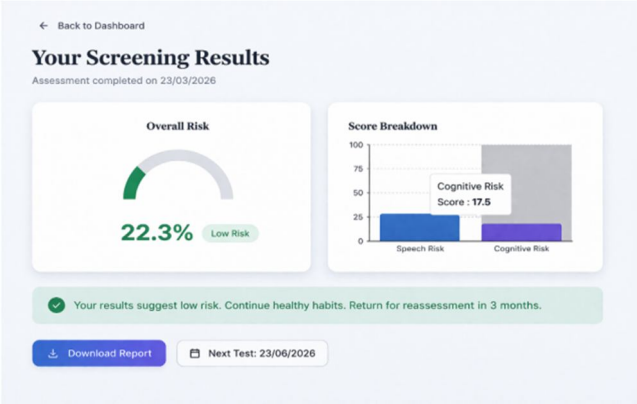


Figure 3: Screening Result

B. Risk Classification Module

This module provides an intuitive visual comparison between speech-based and cognitive-based risks. Graphical visualization is used in this module to demonstrate the importance of features towards the final decision. The contributions of each of the input factors towards the risk outcome can be visualized through graphs like bar charts.

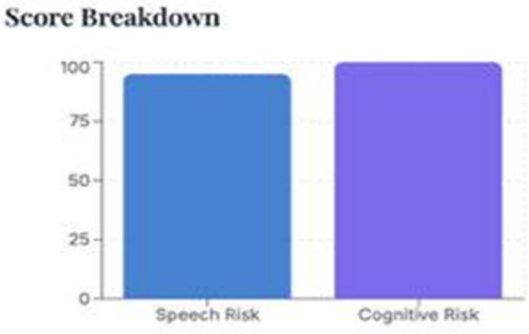


Figure 4: Risk Score

C. Interface for the Screening Task

The interface for the screening task uses speech to obtain input from the user via activities like image description and reading. It collects audio data that will be used for further analysis. The interface should be interactive and easy to use.



Figure 5: Speech Analysis Result

D. Model Evaluation Results

Performance evaluation of the proposed machine learning approach is conducted through the use of several models. The comparative performance of several models, including Random Forest, SVM, Logistic Regression, and Ensemble method, is shown in Figure 6.

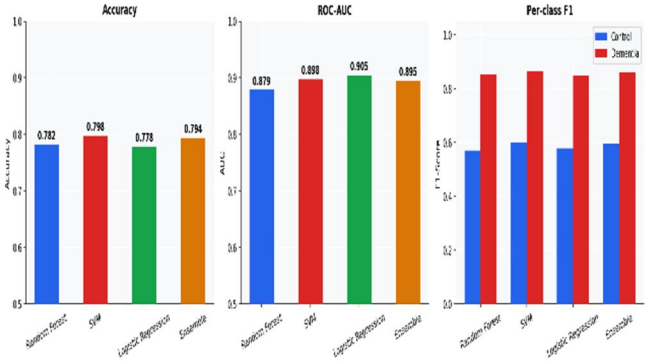


Figure 6: Model Comparison

The above graph gives a comparative analysis on the efficiency of different machine learning algorithms. It is clear that the ensemble algorithm has superior accuracy than the random forest, SVM, and logistic regression.

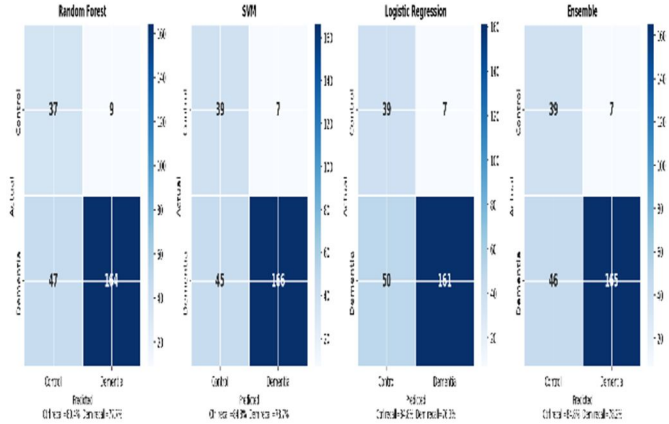


Figure 7: Confusion Matrix

The confusion matrix represents the overall efficiency of the machine learning algorithm through correct and incorrect predictions.

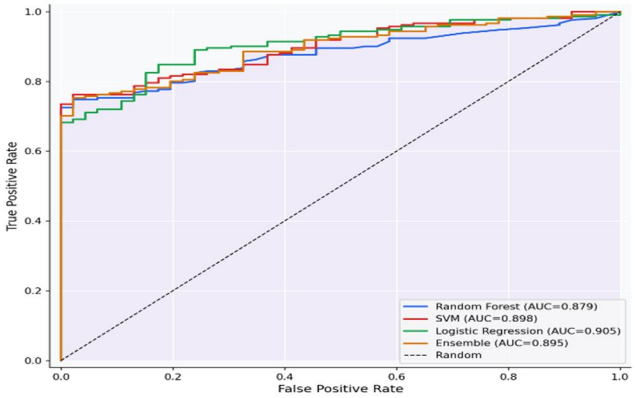


Figure 8: ROC Curve

ROC stands for Receiver Operating Characteristics, which is represented by the above curve. The ROC curve is the relation between the true positive rate and the false positive rate.

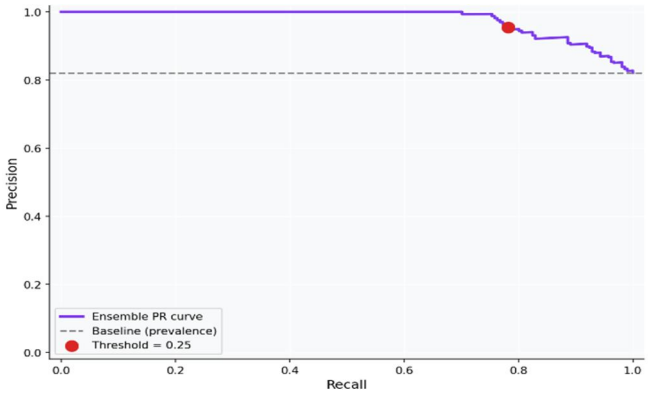


Figure 9: Precision-Recall

This chart shows the compromise between both measures. This will be useful while determining the efficiency of the model, especially in the case of imbalance in the dataset.

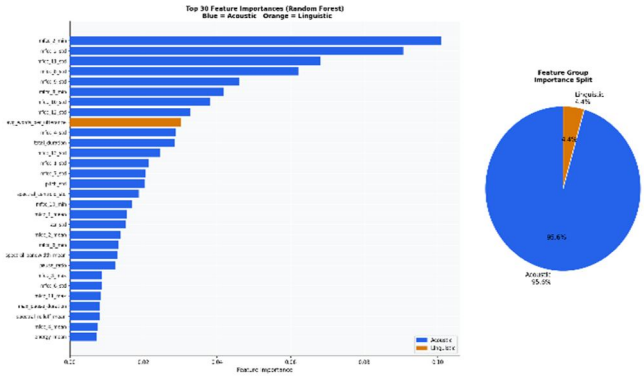


Figure 10: Feature Importance

The below graph represents the most important features for dementia prediction. The chart below shows the features which have high importance in predicting dementia.

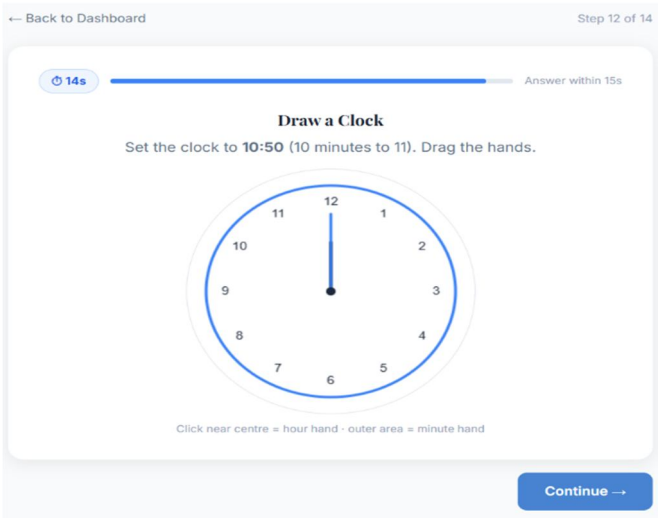


Figure 11: Cognitive Test Interface

The clock drawing test is illustrated in the above diagram and performed in the cognitive testing module.
During this test, participants are required to draw a clock showing a certain time (10:50). This test assesses the visuo-spatial ability,

attention, and cognitive thinking of the participants. It is done for detecting the presence of cognitive impairment among patients with early-stage dementia.

Conclusion drawn after executing the suggested model proves that it is effective in distinguishing dementia cases from non-dementia cases. Analysis of the different types of machine learning models indicates that the suggested ensemble model is more effective as compared to other models. From the significant variables identified in this study, it becomes quite clear that there are various factors that affect the prediction of dementia. From the results, one can conclude that cognitive and speech features play an essential role in the prediction of dementia.

VIII. CONCLUSION

Therefore, it will be reasonable to claim that the described solution could serve as an excellent alternative for diagnosing dementia via the use of machine learning technologies and voice recognition and cognitive testing. At the same time, the presented method will be able to provide risk assessment among its users. The use of the online approach will help prevent expenses related to buying new technical facilities. However, it would be necessary to highlight that this approach will not be utilized as a diagnostic method but rather be used as a means for identifying early symptoms. Some potential methods for further improvement may include the use of deep learning algorithms along with multiple language options.

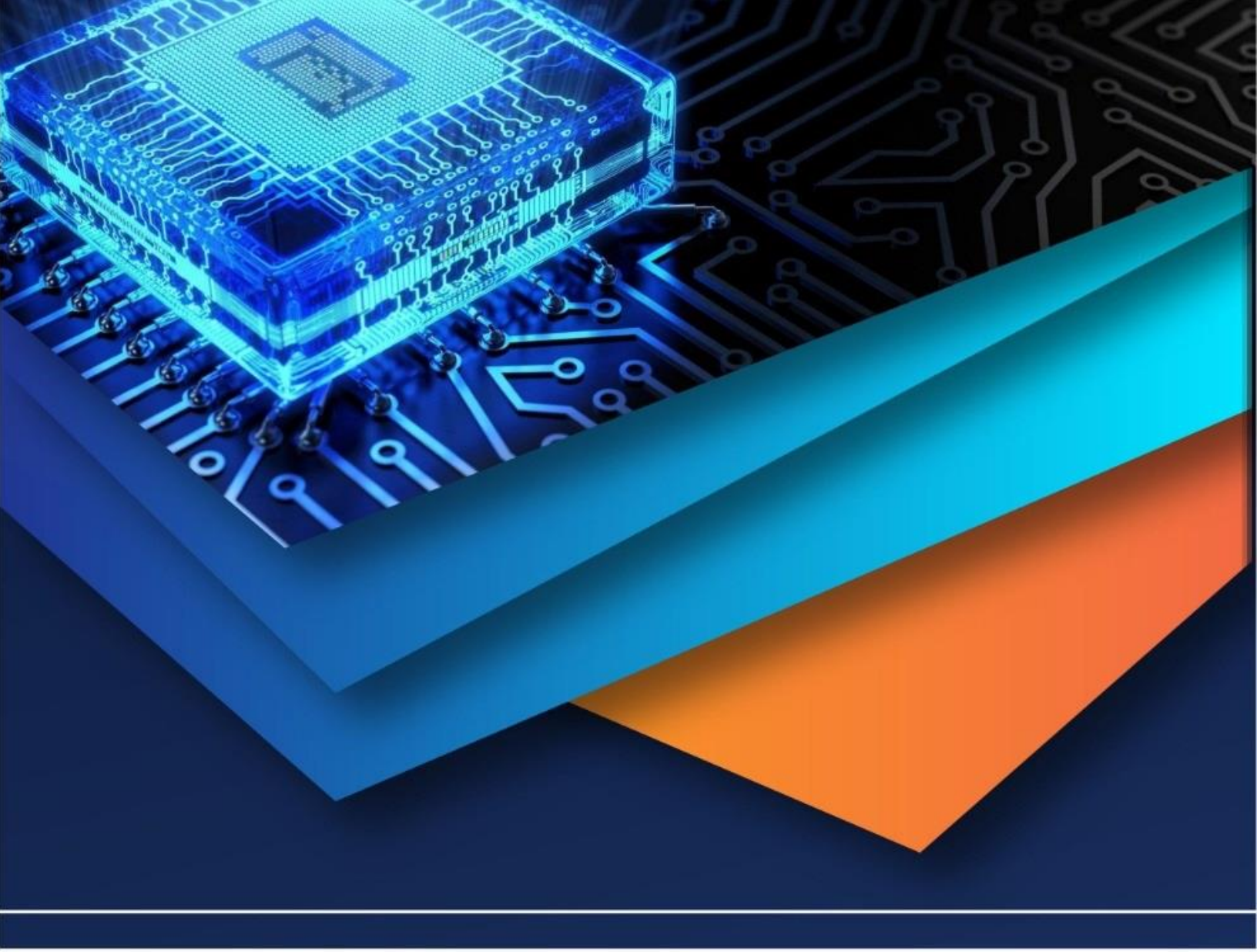
IX. FUTURE SCOPE

The proposed system could also be enhanced by integrating more advanced deep learning techniques such as LSTM and CNN for more precise predictions. The use of larger and more diverse datasets could also make the proposed system more robust and reliable. Furthermore, in the future, the suggested system can be made available as an application that one can install on their mobile phone. Apart from all these aspects, it is also possible to make the suggested system more versatile by incorporating additional languages as well as integrating it with wearable technology in order to monitor it on a continuous basis. All these factors contribute towards the fact that these features can help in making the suggested system better.

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