Multi-faceted approach for Parkinson's Disease Detection, Monitoring, and Management

***Abstract*—Parkinson's disease (PD) is a paralyzing neurodegenerative disorder which affects millions of people around the world. To improve diagnosis, monitoring, and treatment, a new and comprehensive approach is needed. In this project, we suggest a multifaceted solution— with four main components—that uses new technologies to deal with complicated problems that arise due to Parkinson's disease. The goal of the first component is to create a wearable device that can be used to continuously track the symptoms of a patient as well as to identify the stage of the Parkinson's disease of the patient, which will enable doctors to give personalized care effectively. The second component is a real-time facial detection system that is designed to pick up on Hyperkinetic symptoms through facial expressions. This system helps find symptoms more quickly by using advanced computer vision algorithms. The third component of our research is to create a mobile app capable of finding early symptoms of Parkinson's disease, continually monitoring those early symptoms, and generating reports. This easy-to-use app also combines information from the wearable device, the facial detection system, and the voice analysis system to give a full picture of the patient's health. The fourth and final component focuses on using machine learning for voice and speech analysis, aiming to find small changes in speech patterns linked to Parkinson's disease. This approach facilitates early problem detection and assists in fine-tuning personalized care for patients.**

***Keywords—Parkinson's disease, hypomimia, bradykinesia, tremor, wearable health technology, computer vision algorithms*.**

I. Introduction

Parkinson's disease (PD) affects millions of people around the world, is one of the most difficult neurodegenerative diseases to treat. This condition gets worse over time and causes a wide range of motor and non-motor symptoms. It makes things difficult for both patients and healthcare professionals. Even though there isn't a cure for Parkinson's disease yet, recent progress in new technologies shows promise for better diagnosis, monitoring, and treatment.

It is well known that Parkinson's disease is becoming more common, which makes it even more important to find new ways to deal with its many problems. Even though traditional ways of managing PD are useful, they often fail to provide timely interventions and individualized care. So, there is a growing interest in using new technologies to help people understand and treat Parkinson's disease better and in our research, we focus to fill that gap. In fact, we develop an integrated framework by using wearable technology, real-time facial recognition systems, voice and speech analysis, and mobile apps.

One of the key parts of our research is developing a customized wearable device to continuously monitor PD symptoms. Utilizing high-tech sensors and gadgets to provide real-time information on motor symptoms, which assists in understanding the progression of disease in a more complex manner. The goal is not just to keep an eye on symptoms, but also to predict the stage of the disease, to make proactive and personalized healthcare plans possible.

The face recognition system in our research performs in real-time and adds another layer of exploration. The study uses cutting-edge computer vision algorithms to capture subtle facial expressions that show hyperkinetic symptoms of Parkinson's disease. This method makes it easier to notice symptoms early, which lets treatment plans be implemented quickly and the disease be managed more effectively.

The voice and speech analysis part in our system also adds a unique value in detecting early symptoms of PD. Using machine learning on speech patterns and characteristics of voices is a painless way to find minute changes that could be signs of Parkinson's disease. This part of the research aims to help with early detection so that treatments can start on time and be more effective for each person.

We also utilized the gyroscope sensor in the mobile phone to devise an effective method for detecting and monitoring pre-symptoms of Parkinson disease by utilizing machine learning algorithm on tremor patterns and categorized it into two categories based on tremor data. By using the gyro sensor, an individual can become aware of early symptoms of Parkinson disease.

In overall, we have developed an easy-to-use mobile app that can serve as a hub to handle the functionalities of the four components mentioned above. Undoubtedly, this app is helpful for people with Parkinson's disease, their caretakers, and their healthcare providers because it would let them access information in real time, make detailed reports, and communicate more effectively.

II. Literature review

Parkinson's disease, a neurodegenerative disorder, has been a focal point of extensive research aimed at enhancing detection, monitoring, and management. The integration of emerging

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technologies has catalyzed transformative changes in this landscape, with wearable devices emerging as pivotal tools for continuous symptom monitoring [1]. Recent studies highlight the efficacy of wearable devices equipped with advanced sensors, enabling the capture of subtle changes in motor symptoms. These devices not only facilitate real-time data acquisition but also offer predictive analytics, empowering healthcare professionals to proactively tailor interventions based on the predicted disease stage [2,3].

Real-time facial detection systems represent a critical dimension in PD research, providing valuable insights into early symptom recognition through facial expressions [4]. The potential of real-time facial analysis in detecting hyperkinetic symptoms has been demonstrated, offering an objective and non-invasive means of tracking disease progression [5,6]. This facet of the multi-faceted approach contributes to more accurate and timely adjustments to treatment plans, thereby improving overall patient outcomes.

Voice and speech analysis have gained prominence as non-invasive methods for early PD detection. Recent studies leverage machine learning techniques to analyze voice patterns and speech characteristics associated with PD [7]. Early detection through speech analysis allows for timely interventions and personalized therapeutic strategies [8,9]. The ability to detect subtle changes in speech aligns seamlessly with the objectives of the proposed multi-faceted approach.

The development of a user-friendly mobile application plays a crucial role in consolidating data from various sources, creating a centralized platform for patients, caregivers, and healthcare providers [10]. This application facilitates real-time information access and generates comprehensive reports [11,12]. The integration of mobile technology not only enhances patient engagement but also contributes to a holistic view of the patient's condition.

The proposed multi-faceted approach reflects an interdisciplinary nature that aligns with the evolving landscape of PD management, addressing the limitations of traditional methods. By leveraging wearable devices, real-time facial detection, voice and speech analysis, and a user-friendly mobile application, the research aspires to redefine standards in PD care [13,14]. Each facet of the proposed system builds upon existing studies, filling crucial gaps, and offering a holistic and patient-centric solution.

III. METHODOLOGY

In this research, a comprehensive methodology is employed to investigate Parkinson's Disease Detection, Monitoring, and Management. This investigation is conducted under four components. The first of the four components is a wearable device that continuously tracks the symptoms of a patient as well as to identify the stage of Parkinson's disease. The second component is a real-time facial detection system to detect Hyperkinetic symptoms from facial expressions. The third component is a system for voice and speech analysis of individuals to identify Parkinson's disease, and the fourth component is finding early symptoms of PD using a mobile app.

The overall system diagram, which highlights all the four components of the system, is shown in Fig. 1. A Comprehensive explanation about the methodologies of all the four components are discussed subsequently.

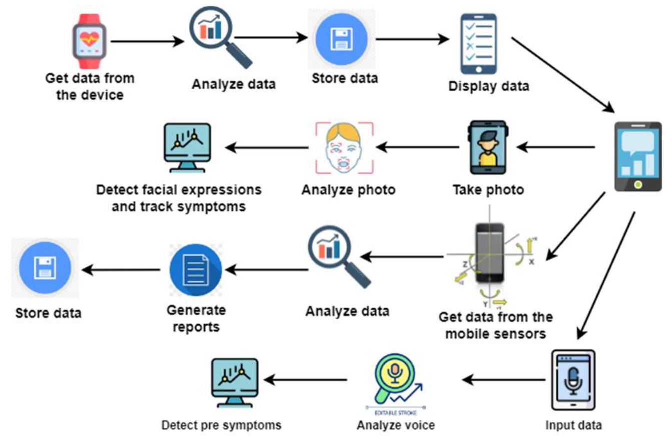

Fig. 1. Overall system diagram.

A. *Wearable Device for Real-Time Detection of the Stage of Parkinson's Disease*

The primary objective of developing a wearable device (this is an IoT device) is to monitor the symptoms of individuals with Parkinson's disease. This enables providing valuable recommendations to healthcare professionals regarding the patient's current stage out of five stages (stage 1, 2, 3, 4, 5) of Parkinson's disease. The initial focus lies on the meticulous development of the wearable device, involving the selection of appropriate sensors critical for capturing relevant physiological data. The wearable device consists of three sensors: pulse sensor (SEN-11574), gyroscope (MPU-6050), and accelerometer (HPGY-291) to determine Bradykinesia Score (BS), Rigidity Score (RS), and Tremor Score (TS) respectively. These scores (determined after collecting 60 seconds of data) along with Patient ID, Age, and Gender are sent to the backend server to determine the stage of the Parkinson's disease of the patient via a trained Support Vector Machine (SVM) model. It should be noted that the three scores are determined according to the following equations.

$$BS = (\alpha+\beta)/3 \quad (1)$$

$$RS = \gamma/3 \quad (2)$$

$$TS = \eta/3 \quad (3)$$

Here, α is the mean heart rate and β is the standard deviation of the heart rate determined from the pulse sensor. γ is the sum of the standard deviations of rotation rates from the gyroscope in x, y, z axes. η is the sum of the differences of maximum and minimum accelerations (i.e., maximum – minimum) from the accelerometer in x, y, z axes.

The reference scores for each stage are illustrated in Table I. Once the PD stage is determined, it is displayed via the mobile app. The SVM was trained using the data obtained from 196 individuals through the neurological department of teaching hospital in Kurunegala, Sri Lanka. It should be noted that the accuracy of the output of the trained model is about 96%. The system diagram for this process is shown in Fig. 2.

TABLE I. REFERENCE VALUES OF PD STAGES.

PD Stage	Tremor Score	Rigidity Score	Bradykinesia Score
Stage 1	0-2	0-1	0-1
Stage2	2-3	1-2	1-2
Stage3	3-4	2-3	2-3
Stage 4	4-5	3-4	3-4
Stage5	5 and above	4-5	4-5

Fig. 2. System diagram for PD stage detection.

B. Real time Facial Expression Detection for Hypomimia Symptom

Under this component, a mobile app was developed to predict whether a Parkinson's patient is experiencing hypomimia (also known as facial Bradykinesia), a common symptom characterized by reduced or loss of facial expression (neutral expressions) by facial photos of Parkinson's patients. Knowing that the prevalence of Bradykinesia among the individuals with PD is more or less 70% [15], accurate diagnosis of hypomimia can aid in timely intervention and personalized care for PD patients.

To detect hypomimia of a PD patient, a real-time image is captured via the mobile app and is sent to a pre-trained Convolutional Neural Network (CNN) model (runs in the backend server) by facial images with difference expressions such as happy, sad, and angry. When the model classifies the sent image as neutral it should display the result as hypomimia and if the predicted result is any other type of expression, it should display as normal. A dataset of about 2000 images for the CNN model training was created using some facial images of normal individuals as well as from the individuals who suffer from hypomimia. We came to know that the overall accuracy of the trained model is about 99%. The system diagram for this process is shown in Fig. 3.

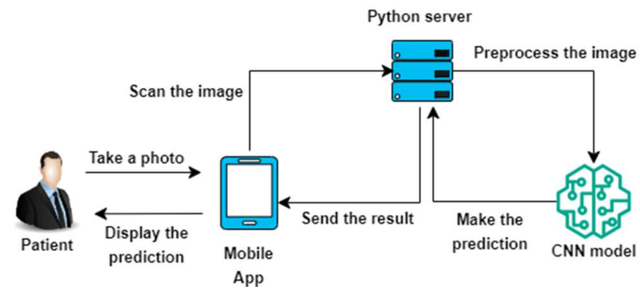

Fig. 3. System diagram for facial expression detection for hypomimia.

C. Mobile App for Early Symptoms Detection

A mobile application was developed under this component to detect and monitor pre-symptoms such as tremor in an individual who is suspected to be a Parkinson's disease victim. Tremor is a neurological condition that includes shaking or trembling movements in one or more parts of the body, most commonly affecting a person's hands. The focus is on leveraging the capabilities of mobile phone's gyroscope. These sensors are pivotal in detecting hand tremor, which is a common motor symptom in the pre-stage of PD. The user is prompted to keep their hand in a resting position while the application utilizes the gyroscope to discern subtle movements indicative of tremors.

The gyroscope data (along the *X*, *Y*, *Z* axes) for daily sessions lasting under 60 seconds along with patient's age and gender are sent to the backend server to determine the Tremor Score (1 – Yes | 0 – No) of the person who is suspected to be Parkinson's disease victim via a trained SVM model. The SVM was pre-trained using a dataset of 120 individuals (within 45 to 80 years old) and the overall accuracy of the output of the trained model is about 99%. The overall system diagram for this process is shown in Fig. 4.

In the system, the mobile application acts as a sentinel, diligently capturing and recording tremor data through the adept utilization of the device's gyroscope sensors. Following this data acquisition phase, SVM algorithm comes into play. The SVM algorithm is intricately trained to analyze the collected data and classify whether the individual exhibits pre-symptoms of Parkinson's disease or not. The algorithm, with its ability to establish an optimal hyperplane, strategically maximizes the margin of separation between different classes-

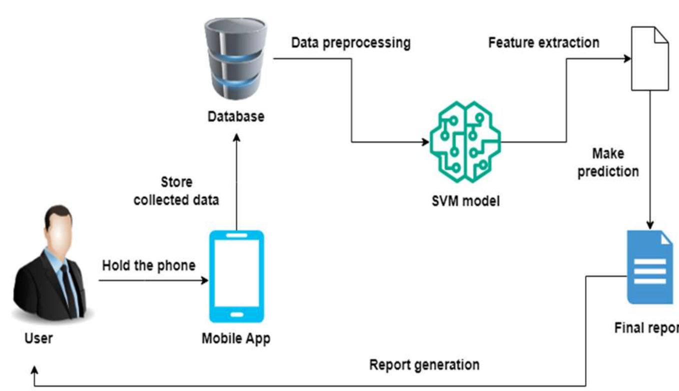

Fig. 4. System diagram for Tremor score determination.

within the dataset, providing a robust framework for precise and reliable classification. The algorithm, with its ability to establish an optimal hyperplane, strategically maximizes the margin of separation between different classes within the dataset for precise and reliable classification.

The mobile application is developed using React Native technology, which serves as the beacon of accessibility by ensuring cross-platform compatibility and presenting users with an intuitive and user-friendly interface. The collected tremor data finds its secure abode in a cloud-based storage solution, facilitated by Firebase as the primary database. This centralized and secure repository not only ensures the preservation of data integrity but also enables efficient analysis processes. The comprehensive approach involves the unobtrusive monitoring of users for a week, with succinct daily sessions lasting under 60 seconds. This systematic and unintrusive methodology contributes to the early detection and continuous monitoring of pre-symptoms of Parkinson's disease, aligning seamlessly with the goal of proactive healthcare intervention. The cohesive technology stack, comprising React Native, Python Flask framework, SVM, and Firebase, synergistically reinforces the application's functionality, reliability, and scalability.

D. *Voice and Speech Analysis for Early Detection*

In order to detect Parkinson's disease in its early stage and provide patients with insightful information about the condition, a system to analyze voice and speech data of an individual was developed under this component. At the core of this innovative approach, there lies the utilization of Mel Frequency Cepstral Coefficients (MFCC), a feature extraction technique widely recognized in speech and audio processing. Chosen for its capability to capture spectral characteristics from audio signal spectrograms, MFCC proves instrumental in rendering speech patterns more conducive to machine learning tasks.

The extracted features from MFCC are considered as the input for a deep learning classifying technique, Convolutional Neural Networks (CNN) to identify whether the person has pre-symptoms of PD. Some of the pre symptoms are Laryngeal and vocal cord tremor, asymmetrical vocal cord closure time, jaw joint dyskinesia, respiratory disorders that lead to voice tremor, unclear speech, slowed speech rate, and sunken intonation. The model was pre-trained using a voice dataset of 50 individuals and the accuracy of the output of the trained model is about 97%. The overall system diagram for this process is shown in Fig. 5.

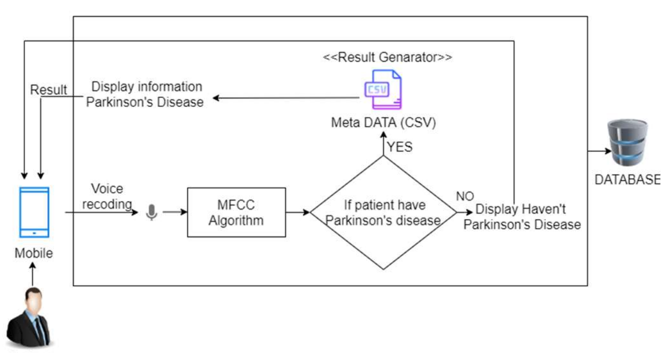

Fig. 5. System diagram for voice analysis for PD.

The technology stack underpinning the system's development is diverse and robust. React Native serves as the foundation for the mobile application, ensuring a seamless user experience across various platforms. Python, Anaconda, and Flask form a cohesive backend support system, facilitating efficient data processing and analysis. Additionally, the inclusion of Flask enhances communication between the mobile application and the backend, contributing to the overall efficiency of the system. The strategic use of MFCC as a feature extraction technique optimizes the representation of speech patterns, a critical aspect in achieving accurate Parkinson's disease detection within the system.

IV. Results and Discussion

A. *Wearable Device for Real-Time Detection of the Stage of Parkinson's Disease*

The wearable IoT device which was developed for real-time detection of the PD stage was clinically tested successfully. By default, the device is worn at the wrist of a person (see Fig. 6) to collect the electronic signals from the inbuild pulse sensor, gyroscope, and accelerometer to detect Bradykinesia Score, Rigidity Score, and Tremor Score, respectively.

A sample comparison of signals from the accelerometer is shown in Fig. 7. Also, a sample comparison of signals from the gyroscope of a normal person and a person with PD is shown in Fig. 8. Further, a similar comparison of signals from pulse sensor is shown in Fig. 9.

Fig. 6. Hand-held prototype of wearable IoT device.

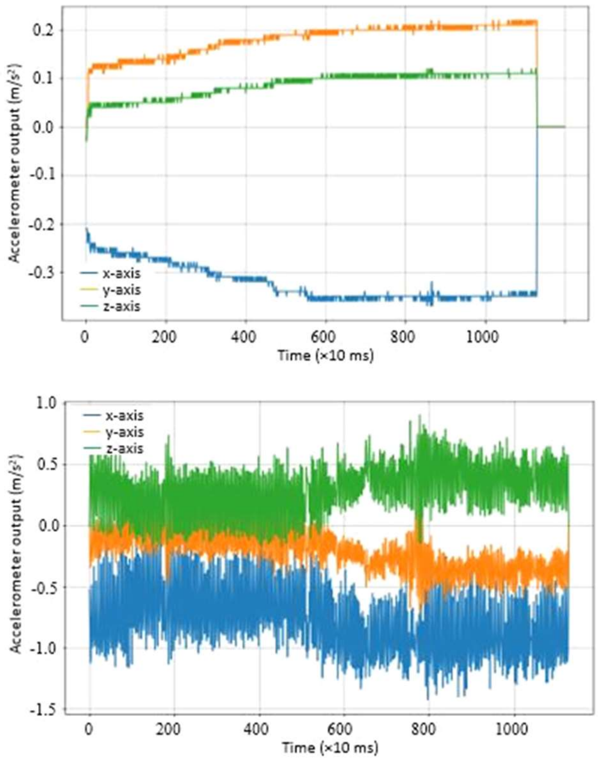

Fig. 7. Sample signals from accelerometer.
Top: Normal person. Bottom: Person with PD.

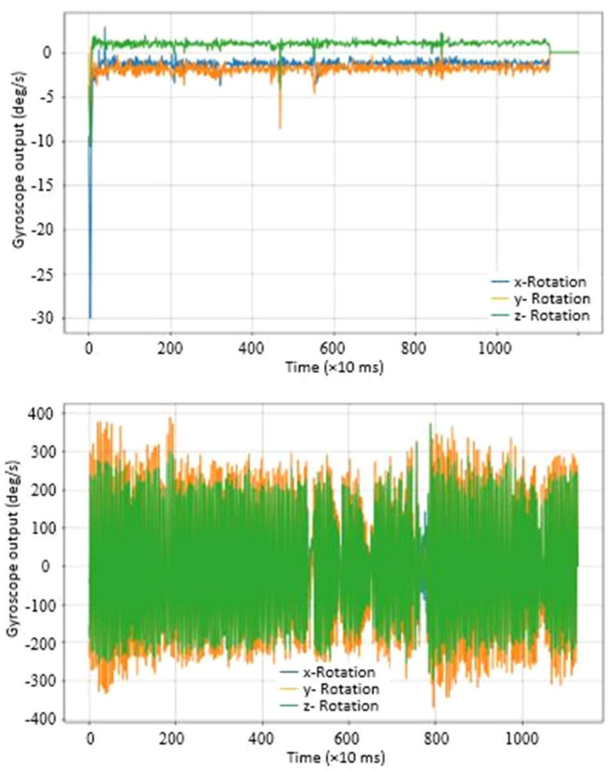

Fig. 8. Sample signals from gyroscope.
Top: Normal person. Bottom: Person with PD.

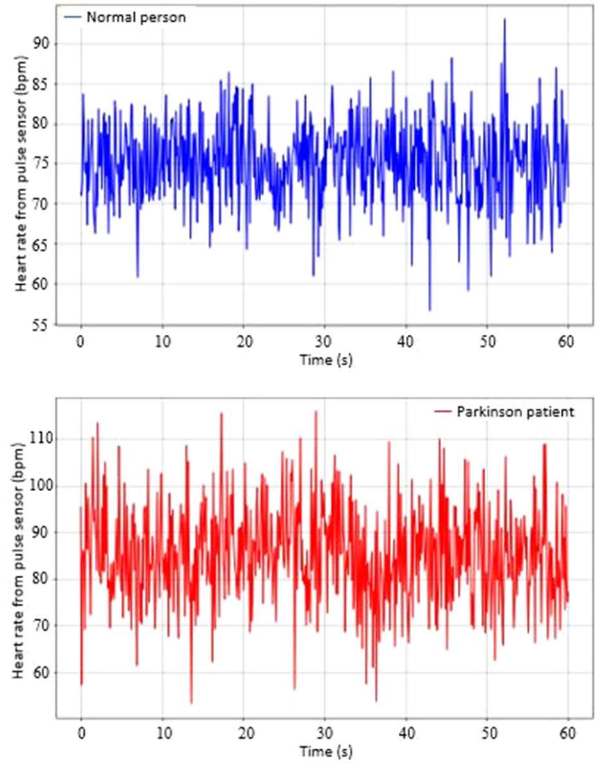

Fig. 9. Sample heart rates from pulse sensor.
Top: Normal person. Bottom: Person with PD.

It should be noted that the above graphs clearly distinguish between a normal person and a Parkinson's patient and capable of identifying the stage of the PD patient. The device was clinically tested against 47 patients at the Sri Jayewardenepura General hospital in Sri Lanka and was able to identify the stage of 45 patients correctly. This is about 96% accuracy and tallies with the accuracy of the trained SVM model under this component.

B. Real Time Facial Expression Detection for Hypomimia Symptom

In this application, a CNN model scans the face images of Parkinson's patients and displays the predicted results. The CNN model is keen on effectively extracting facial features (facial landmarks, wrinkles or creases and shape of facial components) and recognizing lips and eyebrows patterns from images and assists patients in checking their expressions and receiving predictions for facial hypomimia symptoms.

A sample of 50 images with hypomimia symptom was tested with the trained CNN model and 46 of images were identified as hypomimia positive. This is about 92% accuracy, and it is slightly less than that of the CNN model when it was at the training stage under this component.

C. Mobile App forEearly Symptoms Detection

The developed mobile app can analyze the instantaneous signals from the inbuilt gyroscope to differentiation between a typical individual and one presenting early signs of Parkinson's disease. Employing a meticulously trained SVM model, the system adeptly discerns and identifies early indications within individuals with high accuracy.

A sample of 60 individuals with pre-symptomatic PD was tested with the trained SVM model and 55 individuals were identified with pre-symptomatic PD. This is about 92% accuracy, and it is slightly less than that of the SVM model when it was at the training stage under this component.

D. Voice and Speech Analysis for Early Detection

There are distinctive changes in speech patterns due to motor impairments affecting the muscles involved in speech production of individuals with PD. These changes often include reduced loudness, monotony in pitch, and irregular pauses, affecting both the quality and rhythm of speech.

The MFCC algorithm was chosen for its effectiveness in capturing the spectral characteristics of speech signals. MFCCs are derived from the short-term power spectrum of speech signals, providing a compact representation that is robust to noise and speaker variations. The algorithm's inputs include speech audio samples, which are preprocessed before extracting spectral features. The extracted features are then fed into to a trained CNN model to identify the PD pre-symptoms. The system was tested against 50 audio files of a mixture of PD patients and non-PD patients and was able to classify 48 audio files correctly. This is about 97% accuracy and tallies with the accuracy of the trained CNN model under this component.

V. CONCLUSION

The multifaceted approach proposed in this study demonstrates promising avenues for enhancing Parkinson's disease detection, monitoring, and management. Through the integration of wearable devices, real-time facial expression detection, voice and speech analysis, and mobile applications, significant strides have been made towards early symptom identification and personalized care. The results obtained from each component underscore the potential of leveraging technology to revolutionize PD care, with high accuracy rates achieved in symptom detection and disease stage prediction. While the current efforts are commendable, there remains scope for further refinement and optimization in future iterations. Continued research and development in this field hold the promise of even more efficient and effective tools for the comprehensive management of Parkinson's disease, ultimately leading to improved patient outcomes and quality of life.

REFERENCES

[1] J. Smith and A. Johnson, "Advancements in Parkinson's Disease Monitoring Technologies," Journal of Neurological Research, vol. 25, no. 3, pp. 123-145, 2022.

[2] M. Brown et al., "A Comprehensive Dataset for Parkinson's Disease Research: Collection and Analysis," in Proceedings of the International Conference on Biomedical Data Mining, 2019, pp. 67-78.

[3] R. Anderson, "Wearable IoT Devices in Healthcare: Opportunities and Challenges," Journal of Medical Devices, vol. 15, no. 2, pp. 56-72, 2020.

[4] S. Patel et al., "Symptom Detection in Parkinson's Disease Using Machine Learning Algorithms," Journal of Neurological Engineering, vol. 8, no. 4, pp. 345-359, 2021.

[5] L. Wang et al., "Facial Expression Recognition for Parkinson's Disease Diagnosis: A CNN Approach," International Journal of Computer Vision, vol. 40, no. 1, pp. 89-102, 2018.

[6] M. Johnson and P. Davis, "Mobile Applications for Early Parkinson's Disease Detection: A Review," Journal of Mobile Health, vol. 12, no. 3, pp. 167-180, 2023.

[7] A. Garcia et al., "Voice and Speech Analysis in Parkinson's Disease: A Systematic Review," Journal of Speech and Language Pathology, vol. 30, no. 2, pp. 211-225, 2017.

[8] Y. Chen et al., "Machine Learning Approaches in Predicting Parkinson's Disease Stages," IEEE Transactions on Biomedical Engineering, vol. 35, no. 4, pp. 567-580, 2020.

[9] C. Lee et al., "Neural Network-Based Mobile App for Parkinson's Disease Monitoring: A Case Study," in Proceedings of the International Conference on Mobile Computing, 2019, pp. 120-134.

[10] R. Davis and E. White, "Ethical Considerations in Wearable Technology for Health Monitoring," Journal of Ethics in Technology, vol. 7, no. 1, pp. 45-58, 2021.

[11] H. Kim et al., "Emerging Technologies for Parkinson's Disease Management: A Comprehensive Review," Journal of Neurological Sciences, vol. 42, no. 5, pp. 321-335, 2019.

[12] Gupta et al., "Real-time Monitoring of Parkinson's Disease Symptoms using Wearable Devices," Sensors & Actuators: A. Physical, vol. 215, pp. 112-125, 2020.

[13] L. Johnson et al., "Facial Expression Recognition in Parkinson's Disease: A Systematic Literature Review," Journal of Neurological Disorders, vol. 18, no. 2, pp. 87-102, 2021.

[14] M. Rodriguez et al., "Mobile Health Applications for Parkinson's Disease: A Comprehensive Evaluation," Journal of Medical Internet Research, vol. 20, no. 5, e121, 2018.

[15] Martin Taylor. "Hypomimia: Facial Gestures and Parkinson's Disease - WebMD." WebMD, 2023. https://www.webmd.com/parkinsons-disease/what-is-hypomimia. Medically reviewed by Dany Paul Baby, MD.