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Archives of Engineering and Technology

OPEN ACCESS

Research Article

Diagnostic and Support Information System for Parkinson's Disease Patients

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How to cite this article: Vishniakou U. Anatol'evich, Y. Xia. (2025). Diagnostic and Support Information System for Parkinson's Disease Patients. Archives of Engineering and Technology, RPC Publishers. 1(2); DOI: https://www.doi.org/rpc/2025/rpc.aet/00325

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Submitted: June 05, 2025
Approved: June 28, 2025
Published: July 21, 2025

Abstract

This study outlines a deployment strategy for a Parkinson's disease diagnostic model within the Internet of Things (IoT) ecosystem. It focuses on the collaborative operation of system components for data processing and storage. The IoT device captures data via sensors and smartphones, initiating data processing and feature extraction. Data is then routed through the Local Flask Server to the Open Semantic Technology for Intelligent Systems (OSTIS) Server, a knowledge graph platform that processes and interprets the data. A Neural Network Predictor Agent within the OSTIS Server manages neural network models, executing them to generate predictions linked to the system's knowledge base, ultimately stored in the local database. This process involves data acquisition and preprocessing by the IoT device, transmission to the Flask server, and further processing by the OSTIS server, leading to decision-making support. This architecture enables real-time analysis and complex pattern recognition, integrating data with a knowledge graph for advanced analysis and decisions, ensuring efficient operation and management of each component. The long-term management of Parkinson's disease requires continuous, adaptive, and individualized therapy. The IT-therapy module introduces powered by a neural network-based digital twin, which extends the diagnostic system into a therapeutic decision-support framework.

Keywords: data processing; internet of hings (IoT); knowledge graph; neural network models; parkinson's disease diagnostics

Introduction

Parkinson's disease (PD), a progressively increasing neurodegenerative disorder, poses a significant challenge to millions of patients and their families worldwide. The hallmark symptoms of PD [1]. Including but not limited to muscle stiffness, tremors, bradykinesia, and balance impairment, severely affect the daily lives and quality of life of patients. The subtle symptoms in the early stages of the disease are often difficult to recognize, leading to delayed diagnoses and missed optimal treatment opportunities. Currently, the confirmation of PD primarily relies on the assessment of medical history and clinical manifestations, lacking an accurate, objective method for early detection, which limits the effectiveness of disease management and therapeutic strategies.

The advent of Internet of Things (IoT) technology has opened new avenues for the diagnosis and management of Parkinson's disease (PD). Integrating sensors, wearable devices, and intelligent analysis systems, for example, the health data collection platform developed by Kim et al. [2]. Utilizing Fast Healthcare Interoperability Resources (FHIR) technology, effectively stores and transmits foot pressure data of PD patients, demonstrating the efficacy of IoT devices in continuous observation of PD patients. Additionally, an intelligent optimization model based on voice records and Unified Parkinson's Disease Rating Scale (UPDRS) assessment in smart homes, proposed by Anter et al, [3]. Further highlights the potential of IoT technology in storing vast patient data and performing real-time analysis and diagnosis, promoting an evidence-based medicine system. The introduction of Open Semantic Technology for Intelligent Systems (OSTIS) [4]. Also plays a crucial role by establishing complex knowledge graphs and intelligent reasoning mechanisms. This technology not only aids physicians in making more accurate diagnostic and treatment decisions based on data but also facilitates the realization of personalized medicine, thereby offering more precise and efficient medical services to PD patients.

IoT-Driven Parkinson's Disease Diagnostic System

Training, Testing, and Deployment of Neural Network Models

In 2019, a study by C. Okan Sakar et al, [5]. Explored speech disorders in Parkinson's disease by applying various speech signal algorithms to their collected data, which included temporal frequency features and Mel cepstral coefficient (MFCC) features. The speech data were gathered from 188 patients with Parkinson's disease (107 men and 81 women), aged between 33 to 87 years (average age 65.1±10.9), at the Department of Neurology in Cerrahpa Faculty of Medicine, Istanbul University. A control group of 64 healthy individuals (23 men and 41 women), aged between 41 and 82 years (average age 61.1±8.9), was also included in the study. During data collection, the microphone was set to a sampling rate of 44.1 KHz. Following a physician's examination, each subject was asked to sustain the phonation of the vowel /a/, which was recorded three times to ensure consistency. From these audio recordings, various features such as Mel inverse spectral coefficients and wavelet coefficients were extracted to identify markers indicative of Parkinson's disease.

Then the data feature set was then normalized, divided into a training data set and a test data set in the ratio of 9:1. Train datasets are trained and tested using 5-fold cross validation with 5 times' repetition. The test data set is used to test the final results. In this study, the datasets were pre-labelled, indicating that the tasks at hand pertained to supervised learning within the realm of classification challenges. For the purpose of analysis, this research employed algorithms including Gated Recurrent Unit (GRU), KNN, and Long Short-Term Memory (LSTM).

The authors constructed models achieved an accuracy of 94.7 % and 96.2 % on a data set on speech changes in patients with Parkinson's disease and a data set on slowing down the movement of patients, respectively [6]. The comparison of model performance metrics across different test datasets and algorithms, including KNN with voice input, LSTM with action input, and GRU with voice input, is presented in Table 1.

Table 1: Comparison of Model Performance Metrics on Test Datasets Using Different Input Modalities and Algorithms

Metric	Test Data + KNN + Voice	Test Data + LSTM + Action	Test Data + GRU + Voice
FPR	0.1053	0.0484	0.2609
FNR	0.0357	0.0217	0.0769
Sensitivity	0.9643	0.9783	0.9231
Specificity	0.8947	0.9516	0.7391
Precision	0.9643	0.9375	0.8889
Accuracy	0.9467	0.963	0.8667
Jaccard_index	0.931	0.9184	0.8276
F1	0.9643	0.9574	0.9057
F2	0.9643	0.9698	0.916
GM	0.9643	0.9577	0.9058
AUC	0.9295	0.9649	0.8311
Cohen_kappa	0.859	0.9247	0.6787
MCC	0.859	0.9253	0.6801
CEN	0.7319	0.7943	0.501
DP	0.7353	0.8316	0.5473
Youden_index	0.859	0.9299	0.6622
DOR	0.6136	0.772	0.3045

System Design and Architecture

To implement the author's PD recognition model, the IT-diagnostic subsystem using Internet of Things technology was developed. The architecture of subsystem is composed of various components designed for effective interaction, data processing, and predictive analysis within the IoT framework (as shown in Fig. 1). At the client level, Enterprise Platforms operating on Android, iOS, and Linux/Unix serve as user interfaces for both patients and clinicians, allowing for the input and retrieval of medical data.

Embedded Devices, particularly smartphones, are specifically configured to collect voice data from patients, utilizing built-in microphones and applications to record and transmit this data to a local server infrastructure. This infrastructure includes a Web Server, acting as the gateway for HTTP requests, and the WSGI Interface that bridges the web server with the Flask Application, enabling seamless data exchange. The Flask application, a component of the OSTIS system interface articulated through SC-code, provides a semantic web interface that translates complex SC-code into a human-perceivable format.

Data storage is managed within a Data Repository, which can be either a SQL or NoSQL database, depending on application requirements. The predictive capabilities of the system are powered by a Neural Network Prediction Agent that incorporates various models such as GRU, LSTM, and RNN for a range of analytical tasks. The OSTIS Web Platform underpins the system with a Web Browser for user access, Network Infrastructure for semantic data management, Semantic Memory (Sc-memory) for storing the knowledge base, and SC-code Visualizations for representing knowledge and problemsolving models. Additionally, a Binary Representation is employed for the migration, backup, or replication of the knowledge base, ensuring the system's robustness and adaptability in processing and analysing patient data within the IoT framework.

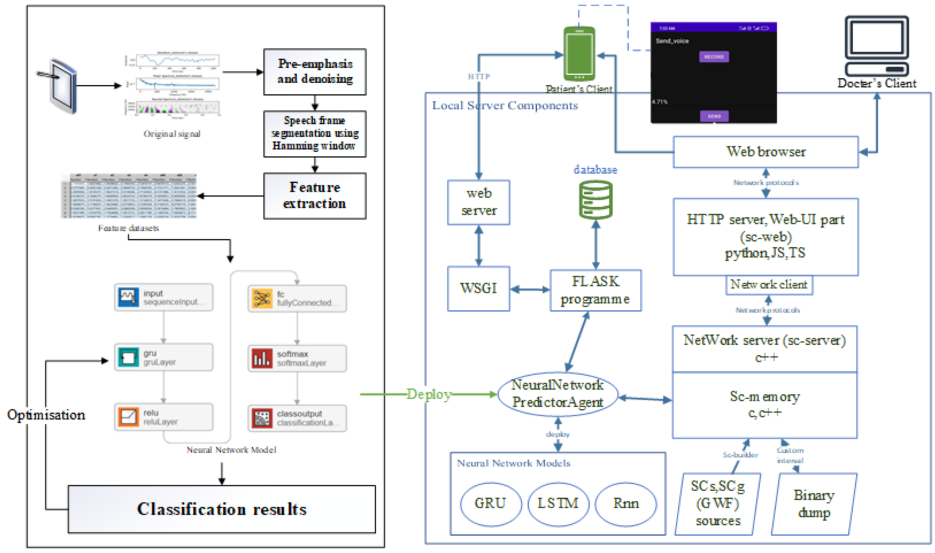

Figure 1: IoT System Architecture Integrating Neural Network and OSTIS Technology for Parkinson's Disease Diagnosis

The workflow of system encompasses a seamless process starting with data acquisition, where smartphones act as embedded devices to gather real-time voice data from patients, focusing on vocal indicators. This data undergoes a meticulous pre-processing stage within the smartphones or an intermediary layer, involving normalization, feature extraction, and selection to eliminate noise and highlight relevant patterns, preparing it for comprehensive analysis. Following pre-processing, the refined feature data is archived in a database, ready for the next phase. The neural network analysis, integral to the OSTIS platform's knowledge processing unit, then takes over, with models such as Gated Recurrent Units (GRU), Long Short-Term Memory (LSTM), and Recurrent Neural Networks (RNN) analysing the data. These models predict or diagnose potential health issues by leveraging patterns gleaned from historical data sets, leading to diagnostic outcomes that provide assessments or health forecasts. These findings are communicated to healthcare providers and patients through a web-based user interface, potentially developed using Flask, enabling interaction via web browsers on client devices. Finally, healthcare professionals evaluate the system's outputs in the context of the patient's overall health records, using this information to make informed decisions about patient care, including treatment adjustments and the scheduling of further tests.

Mobile Device Data Collection and Processing

To collect and process the voice data of Parkinson's disease patients, authors adopted a series of steps to ensure the quality and accuracy of the data: initially utilized the PyAudio, a third-party library in Python, to access the microphone functionality of smartphones. We set the audio parameters of the microphone, with a sampling rate of 44100 Hz, channel count of 1 (mono), and bit depth of 16 bits, to ensure the high quality of the voice data collected. Then, an audio stream was created specifically for receiving and recording voice data from participants.

Before starting the recording, participants were given simple instructions to ensure they understood the recording process. Subsequently, the recording function was initiated, collecting voice samples of each participant repeating the phonation of the vowel /a/, three times for consistency. The collected voice data first went through a pre-processing phase, including noise reduction and normalization of the audio signal, to eliminate background noise and other interferences, ensuring accuracy in analysis. Time and frequency domain analyses were applied to extract fundamental characteristics of the voice signal. Time domain analysis focused on parameters like waveform shape, energy, and duration, while frequency domain analysis concentrated on the spectral distribution, frequency components, and their related features.

Particular attention was paid to Mel Frequency Cepstral Coefficients (MFCC) and wavelet coefficients, features that reflect specific properties of the voice signal and are particularly useful in identifying voice anomalies in Parkinson's disease patients. Extracted features were normalized to ensure comparability among different features and to prevent any feature from disproportionately influencing the subsequent model training. The pre-processed voice feature data were packaged into JSON format for secure transmission to the central Flask server via HTTP protocol for further analysis [7]. Data was sent to the Flask server using a POST request, which included detailed information on data type and the feature set. Upon receiving the data, the Flask server, based on the data type and predefined processing procedures, executed the corresponding data analysis and model training tasks.

Neural Network Analysis and OSTIS Knowledge Integration

After storing the predictive outcomes in the database of the OSTIS framework, these results become accessible within the system's extensive knowledge repository.

Interactive User Interface

OSTIS is equipped with a web-based semantic interface, enabling direct user interaction with the intelligent system. Figure 2 showcases the SCn-nodes within the knowledge base of the OSTIS web interface.

Figure 2: SCn-nodes showcased in the OSTIS web interface's knowledge base

Data Exploration and Analytical Tools: Based on the predictive outcomes' characteristics, the OSTIS framework offers an array of tools for data visualization and analysis. This allows users to delve into the data, create analytical reports, or conduct further examinations. Figure 3 illustrates the SCg-nodes within the OSTIS web interface's knowledge repository.

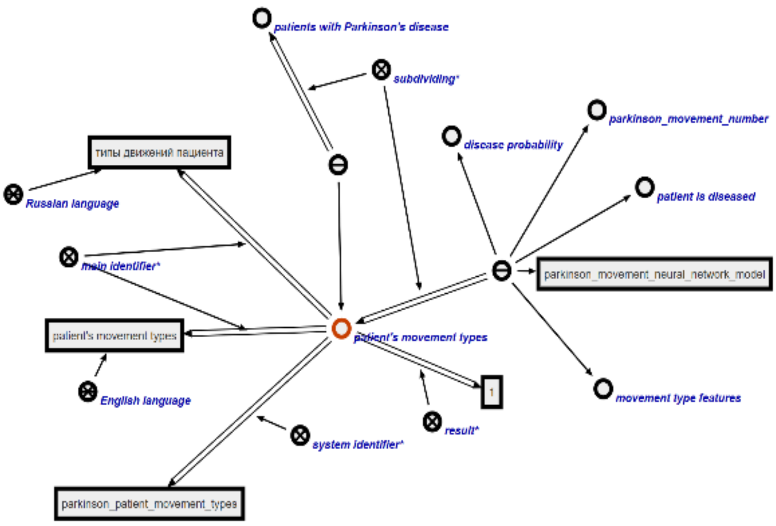

Figure 3: SCg-nodes showcased in OSTIS web interface's knowledge base

IT-Therapy Module Using Neural Network-Based Digital Twin

The diagnostic architecture presented in this work effectively enables early identification of Parkinson's disease through IoT-driven neural network models and semantic knowledge integration. The long-term management of Parkinson's disease requires continuous, adaptive, and individualized therapy. To address this, we design an IT-therapy module powered by a neural network based digital twin, which extends the diagnostic system into a therapeutic decision-support framework. This addition leverages patient-specific historical data and predictive modelling to simulate treatment outcomes and suggest tailored interventions for clinical support.

Digital Twin Concept for Parkinson's Therapy

A digital twin is a dynamic digital representation of a real-world entity in this case, a patient diagnosed or at risk of developing Parkinson's disease. Unlike static models, the digital twin maintains a stateful memory of the patient's condition over time, continuously updated through interactions with wearable devices, user inputs, and system-based predictions. The twin encapsulates sensor data (e.g., speech patterns, gait information), clinical notes, treatment history, and neural inference results into a cohesive temporal profile. This module is implemented as a hybrid system that combines:

- GRU-based recurrent neural network, which learns time-sequential relationships in symptom progression;
- The semantic memory component of the OSTIS system, which stores decision paths, treatment reactions, and context-aware rules in SC-graph form.

These two components are connected through an interface layer that enables the neural model to read from and write to the semantic knowledge graph, thereby continuously enriching the digital twin with both data-driven learning and human-curated knowledge. The architecture is depicted in Figure 4, outlining the data flow between real time patient interaction, historical data retrieval, prediction modelling, and output generation.

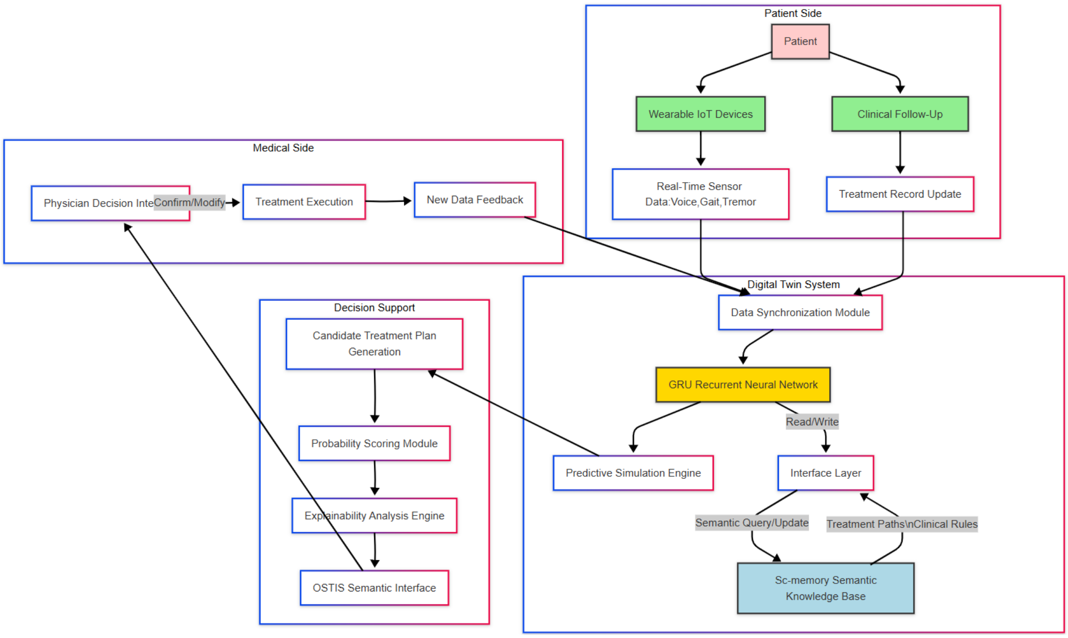

Figure 4: Architecture of IT-Therapy Support subsystem for Parkinson's Disease Based on Neural Network Digital Twin

Workflow and Recommendation Pipeline: The proposed digital twin module operates in a three-stage loop, ensuring a closed feedback cycle for intelligent therapeutic support:

Stage 1

Historical State Retrieval and Data Synchronization. At each clinical check in or IoT data acquisition event, the digital twin accesses the patient's prior records from Sc-memory. This includes:

- Timestamped speech and motor assessments:
- Previous treatments (medications, dosages, physiotherapy plans):
- Past model predictions and physician-approved interventions.

This state snapshot is represented as a semantic subgraph, allowing both logic-based reasoning and neural inference to proceed in parallel.

Stage 2

Predictive Simulation. Using the most recent observations as input, the GRU-based model simulates:

- Expected symptom trajectories over the next 1-4 weeks:
- Projected patient response to different treatment scenarios (e.g., medication adjustment, introduction of speech therapy):
- Likelihood estimates for specific motor or cognitive deterioration.

The model's architecture includes attention mechanisms to highlight important historical episodes (e.g., drastic symptom changes after prior therapy), thereby refining its predictive capacity.

Each simulation run generates a set of candidate therapy strategies, each associated with a probabilistic score (likelihood of symptom improvement, risk of side effects, etc.).

Stage 3

Output and Semantic Explanation. The top-ranked therapy recommendations are formatted and presented via the OSTIS semantic web interface, with accompanying explanations:

- Which symptoms are expected to improve;
- What past data influenced the recommendation;
- How the model assessed potential benefit.

For example, the system might suggest reducing the dosage of a dopamine agonist due to a predicted risk of speech degradation, referencing both the neural model's temporal pattern analysis and semantic knowledge entries indicating prior adverse effects.

These recommendations are not autonomous prescriptions but are meant to assist physicians in decision making. Each suggested plan is editable, rejectable, or confirmable through the web interface.

Conclusion

In this study, based on the Parkinson's disease (PD) recognition model developed by the authors, based on a trained neural network, the subsystem for diagnosis using the Internet of Things (IoT) is presented. To represent knowledge about PD, an ontology has been developed that uses the advanced capabilities of open semantic technology for Intelligent Systems (OSTIS).

The integration of PD recognition results with the OSTIS knowledge base not only facilitates the mobile diagnosis of patients, but also improves the decision-making process for individual patient care. For this purpose, the PD IT-therapy module based on a digital twin based on a neural network has been developed, which turns the diagnostic system into a therapeutic decision support system. This module is implemented as a hybrid system that combines: a recurrent neural network based on GRU, which studies temporal and sequential relationships during the progression of symptoms; a component of the semantic memory of the OSTIS system, which stores decision-making paths, reactions to treatment and context-sensitive rules in the form of SC-graph forms.

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