# BiGaitNet: Deep CNN-Based Classification of Parkinson's Disease Gait Abnormalities Using a Smart Insole Robust to Fewer Plantar Sensors

Eun-Seo Park, Xianghong Liu, and Chang-Hee Han*
Dept. of Computer and Information Science, Korea University, Sejong, Republic of Korea
E-mail: esp0117@korea.ac.kr
E-mail: liuxh@korea.ac.kr
*E-mail: changheehan@korea.ac.kr Tel: +82-44-860-1346

***Abstract*—To enable early diagnosis of Parkinson's disease (PD), gait analysis has gained attention, and smart insoles provide a practical solution for real-time gait monitoring. To address limitations like short battery life and reduced durability caused by numerous sensors in a smart insole, we developed a novel deep convolutional neural network (CNN). This CNN independently analyzes each foot's gait pattern, capturing spatial and temporal features. Tested on a public dataset, our model achieved 84.74% accuracy using only 8 of 32 sensors, outperforming traditional CNNs by approximately 8%. This demonstrates the potential of our CNN for efficient and practical PD gait detection with fewer sensors.**

## I. Introduction

Parkinson's disease (PD) is a progressive neurological disorder affecting movement, with early diagnosis crucial for managing its initial responsive phase. Traditional diagnostic methods are often costly and detect symptoms late, driving interest in gait analysis for earlier detection of abnormal walking patterns. Smart insoles offer a practical solution for real-time gait monitoring, overcoming limitations of traditional methods like motion capture systems. This study introduces a novel deep convolutional neural network (CNN) model designed for smart insoles, achieving high performance with fewer sensors by analyzing each foot's gait to capture spatial and temporal features. The model aims to enhance accuracy, improve battery life, and ensure durability for effective PD gait detection.

## II. Materials and Methods

This study used a public smart insole dataset from 29 participants (13 healthy, 9 elderly, 7 PD patients) with 16 pressure sensors per foot [1]. Data was collected at 100 Hz on a 10-meter path, including gait cycle annotations. IRB approval was obtained (Protocol No. IRB-2025-0082). To use fewer sensors, the foot was divided into forefoot, midfoot, and hindfoot region of interests (ROIs). Performance was evaluated using all 32 sensors versus 8 sensors. Unit step analysis compared gait patterns of healthy adults, elderly individuals, and PD patients, defining a unit step from initial ground contact to the next same-foot contact. Data was segmented, imputed, and normalized to 107 time samples for comparison. Visualizations highlighted group differences, confirming distinct gait characteristics. A sliding window approach (2-second segments, 50% overlap) was used for real-time practicality. Segments with missing data were removed, resulting in 542 (healthy), 525 (elderly), and 172 segments. Datasets were balanced to 172 segments each, shuffled, and formatted into a 516 x 32 x 200 feature vector. A deep CNN was developed to capture spatial and temporal gait features with fewer sensors, considering left/right foot asymmetry. It comprises temporal (T), spatial (S), spatiotemporal (H), and unified (U) convolutional layers, optimized for performance. The model uses a sequence of six 2D convolutional layers, with batch normalization, ReLU, and dropout. A control model with a UTTTTT sequence was used for comparison [2]. The final output categorizes data into S, EL, and PD.

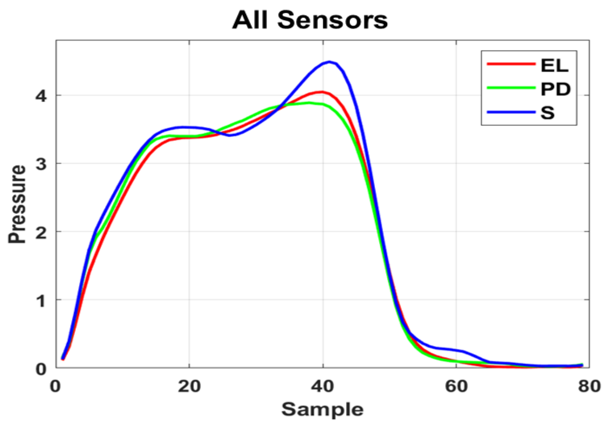


Fig. 1 Average unit step graph for comparing gait patterns.

## III. Results

Fig. 1 shows the averaged unit step graphs of healthy individuals, elderly individuals, and PD patients. A visual comparison of the unit steps throughout a gait cycle suggests differences between groups in pressure patterns. For instance,

Table 1. Evaluation Metric for classification using all sensors. Sensitivity, specificity, and F1-score were calculated using the macro average method.

| | Control Model | Proposed Model |
|---|---|---|
| Accuracy | 93.22 | 97.09 |
| Sensitivity | 93.22 | 97.09 |
| Specificity | 96.61 | 98.55 |
| F1 Score | 93.21 | 97.09 |

healthy individuals present relatively greater pressure peaks, suggesting a more powerful and rapid ability to shift weight when walking.

Table 1 shows the classification performance of the control and proposed CNN models using all 32 sensors. The proposed CNN model achieved a classification accuracy of 97.09%, approximately 4% higher than the control model. Furthermore, the proposed CNN model outperformed the control model in all performance metrics of sensitivity, specificity, and F1-score.

Fig. 2 shows the confusion matrices comparing the control and the proposed CNN model using all 32 sensors. The proposed model achieved higher classification accuracy for all groups compared to the control model. These results indicate that the proposed model outperformed the control model in classifying each of the three different groups.

Fig. 3 compares the classification performance of the control and proposed models across different ROIs only using eight sensors on both feet. The proposed model achieved an average accuracy of 84.74%, which was approximately 8% higher than the control model's average accuracy of 76.14%. Specifically, the proposed model showed the highest accuracy of 89.31% in the hindfoot region. Additionally, the proposed model consistently outperformed the control model in all three ROIs, indicating that independently analyzing each foot's data

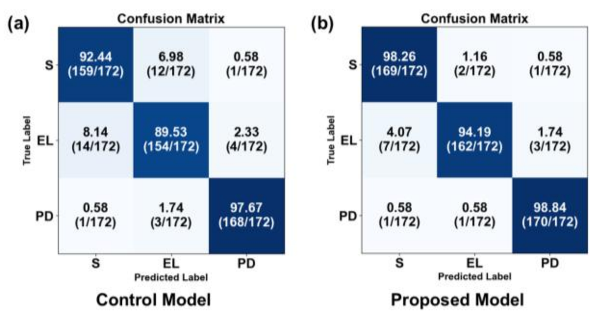


Fig. 2 Confusion matrix results of the control model and the proposed model.

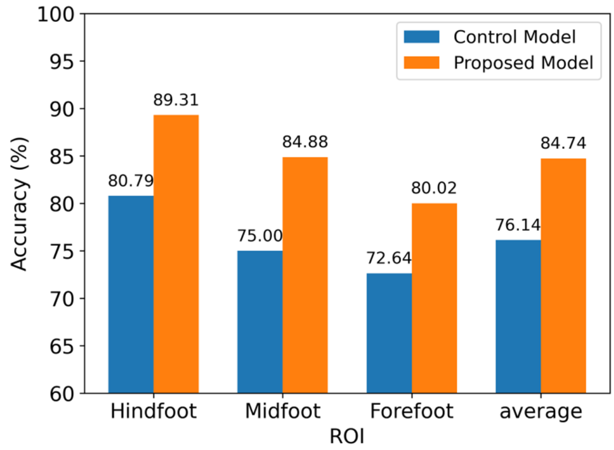


Fig. 3 Comparing the classification performance in ROIs.

significantly enhances overall classification performance when we use the reduced number of sensors in a smart insole.

## IV. Conclusions

In this study, we developed a novel deep CNN model for classifying abnormal gait patterns in PD patients using a reduced number of pressure sensors embedded in smart insoles. The proposed CNN independently analyzes gait patterns from each foot and then integrates these patterns to achieve high classification performance with minimal sensor input. Experimental results demonstrate that the proposed CNN model effectively captures bilateral and asymmetric gait characteristics in PD patients, outperforming the control model. Notably, the hindfoot region produced the highest classification accuracy, providing valuable insights for optimizing future sensor placements. Additionally, the proposed CNN model provides practical benefits, such as simplified hardware, lower manufacturing costs, and improved long-term wearability due to fewer embedded sensors in smart insoles.


## V. Acknowledgment

This research was supported by the National Research Foundation (NRF) funded by the Korean government (MSIT) (No. RS-2024-00455484) and by the MSIT (Ministry of Science, ICT), Korea, under the National Program for Excellence in SW-Centered University (2024-0-00036).


## References


[1] C. Chatzaki, V. Skaramagkas, N. Tachos, G. Christodoulakis, E. Maniadi, Z. Kefalopoulou, D. Fotiadis, and M. Tsiknakis, "The smart-insole dataset: Gait analysis using wearable sensors with a focus on elderly and Parkinson's patients," *Sensors*, vol. 21(8), 2821, April 2021.

[2] S.-S. Lee, S. T. Choi, and S.-I. Choi, "Classification of gait type based on deep learning using various sensors with smart insole," *Sensors*, vol. 19, 1757, April 2019.