A Study on Gait-based Parkinson's Disease Detection Using a Force Sensitive Platform

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Abstract—**Gait analysis aims to study human motion and its potential association with chronic diseases, such as Parkinson's disease and hemiplegic paralysis, by extracting various gait characteristics. It has been a challenging problem to accurately extract temporal and spatial gait parameter and to explore the relationship between gait signal and a disease of interest. In this study, we introduce a gait sensing platform that can capture human movement and classify patients with Parkinson's disease from healthy subjects. Specifically, we first show the platform that consists of force sensitive pressure sensors. Second, we extract gait features from the gait signal collected from the platform. Finally, we collect experimental data from 386 volunteers, including 218 healthy subjects and 168 patients with Parkinson's disease, and conduct extensive experiments to show the possibility of classifying Parkinson's disease patients at a high confidence level. Experimental results of nine different classifiers show that the random forest model outperforms the other eight competitors and obtains an accuracy of 92.49%, demonstrating the power of quantitative gait analysis in the early detection of Parkinson's disease.**

Keywords—Gait cycle; Gait parameter; Gait analysis; Parkinson's disease; Random forest

I. INTRODUCTION

Gait analysis or human gait assessment is to systematically study human movement and aims at quantifying gait characteristics with various temporal and spatial gait parameters, such as stride speed, stride length, step length, cadence, standing time, double support time, and swing time [1]. Furthermore, researchers have pointed out that gait is linked to the functional health of an individual and can be an indicator for the occurrence of a disease and for rehabilitation feedback [2, 3]. For example, previous studies have shown that the elderly with central dysfunction have a higher rate of disordered walking and instability [3]. Accordingly, gait analysis has been drawing researchers from many fields with the aim to study human movement mechanism and facilitate health evaluation and medical decision-making.

In gait analysis, researchers have explored different types of sensing technologies to measure human gait. Generally, we can group existing methods into two categories: vision-based methods and sensor-based methods. Vision based methods rely on a camera to capture human movement and extract different gait parameters. One major drawback is that they suffer from illumination variations and background change. For sensor based methods, they benefit from the development of sensor technology to build sensing units to analyze human kinematics and kinetics. For example, Yoneyama et al. [4] constructed a gait analysis system with a trunk-mounted acceleration sensor, and utilized the cross-correlation and identified the acceleration signal with high intensity, periodicity, and biphasicity as a possible gait sequence. They then applied the system to Parkinson's disease assessment. Klucken et al. [5] constructed a biosensor based embedded gait analysis system to objectively and automatically classify specific stages and motor signs in Parkinson's disease (PD). Although many efforts have been done, how to accurately extract gait parameters remains a challenging problem.

In this study, we present a gait sensing platform that consists of force sensitive sensors. The gait sensing platform enables us to automatically obtain gait signal in real time. Then, we detail spatio-temporal gait parameters that we can accurately obtain with the platform. Particularly, we consider the influence of human body height on the calculation of gait features, such as velocity and cadence. Finally, we apply the system to the detection of Parkinson's disease as a case study and conduct a comparative study of the performance of nine different classifiers in classifying Parkinson's disease.

The rest of this paper is organized as follows. Section 2 introduces the platform and presents the gait parameters. Section 3 describes the experimental setup and presents experimental results. The last section concludes this study.

II. GAIT ANALYSIS

A. Gait sensing platform

The self-developed gait sensing platform is a u-shape electronic walkway that consists of flexible force sensitive pressure sensors. It is comprised of 14 pressure pads (0.8m*0.8m in size, 4 pressure points per cm^2, sampling frequency 100Hz), 5 pressure stations (0.8m*0.8m in size, sampling frequency 500Hz), a balance tester (0.8m*0.8m in size, sampling frequency 500Hz), and 2 ramp modules (0.8m*1.0m in size). The ramp modules are placed at the beginning and end parts of the walkway for users to adapt to the platform. Each plantar pressure pad contains 25,600 pressure sensors placed in a grid array of 1.6m*1.6m. Particularly, each plantar pressure pad has four layers: one layer for load bearing, one layer for holding flexible pressure sensors, and two layers for protection. In addition, each plantar pressure pad connects to a host computer for data storage and analysis. Also, the plantar pressure pads are interconnected to each other with a network cable and a switch. Fig. 1 presents the u-shape electronic walkway that we build for capturing human movement.

The data collected by the platform is then transmitted to the host computer through the network layer. The task of network layer is to receive and synchronize data from different pressure pads. The middle layer running on the host computer extracts a variety of temporal and spatial gait parameters covering both kinetics and kinematics for further analysis. Particularly, we observed differences in human movement patterns when users walking on the curve part of the u-shape walkway. Therefore, we consider gait parameters associated with the situation where one walks on the curve part of the u-shape walkway. The application layer runs on the middleware layer, where we can analyze and visualize the collected sensor data and develop corresponding applications. Herein, we take PD as an application scenario and explore the possibility of classifying Parkinson's disease patients.

B. Gait feature extraction

There are considerable work on what gait features to extract and how to extract or obtain gait features [6]. In this study, according to gait characteristics and the features of the developed platform, three types of gait parameters are extracted: demography information, spatio-temporal gait parameters, and turning gait parameters (related to the case when people walking on the curve part of the u-shape walkway). Since human gait is highly relevant to age, gender, height, and weight, demography information is collected. For example, the cadence of an adult is usually faster than the elderly. For the spatio-temporal gait parameters, we extract the following features from each foot: step length, stride length, gait velocity, cadence, stance time, swing time, pre-swing time, and also extract gait cycle and double support time associated with two feet. Considering that walking on a curve walkway is different from walking on a straight walkway, we obtain gait parameters associated with the situation where one walks on the curve part of the u-shape walkway. Table 1 lists the features.

Table 1. Gait parameters

Demography features	Gait feature	
Age	Step length (cm)	Pre-swing time (ms)
Gender	Stride length (cm)	Gait cycle (ms)
Weight (kg)	Gait velocity (m/s)	Double support time (ms)
Height (cm)	Cadence (steps/s)	Turning time (ms)
	Stance time (ms)	
	Swing time (ms)	

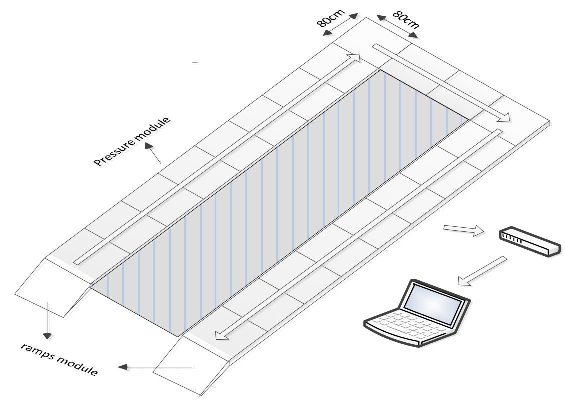


Figure 1. The u-shape electronic walkway.

III. EXPERIMENTAL RESULTS

This section illustrates the experimental setup and presents a comparative study of the performance of nine different classifiers in classifying PD using the data collected by the platform.

A. Experimental setup

The purpose of this study is to extract gait parameters and use them for PD detection. Correspondingly, we recruited volunteers and collected data when they walked on the u-shape electronic walkway. All volunteers had signed an informed consent before participation and all tests were completed under the supervision of two doctors. The healthy subjects without known body and brain injuries were recruited, and the PD patients did not take any medicine within 24 hours before the test. During the test, volunteers were asked to walk on the u-shape electronic walkway on their own way.

In this study, we collected experimental data from 168 patients with Parkinson's disease (males: 88, females: 80) and 218 healthy subjects (males: 103, females: 115). The average height of PD male and female are 166.6cm and 154.7cm, respectively, and the average height for healthy male and female groups are 172.1cm and 158.9cm, respectively. The mean age of PD male (female) group is 58.9 (64.4) years and the mean age healthy male (female) group is 34.2 (41.6) years.

B. Classification performance

After collecting experimental data, we extract gait features as listed in Table 1. In order to evaluate the role of gait analysis in Parkinson's disease detection, we used nine classification models with different metrics, including Naïve bayes (NB), *k*-nearest-neighbor (KNN) with *k*=3, support vector machine (SVM) with linear kernel, decision tree (C4.5), linear discriminant analysis (LDA), quadratic discriminant analysis (QDA), adaboost (ADA), subspace technique (SUB), random forest (RF) with 50 trees. Three-fold cross-validation technique is used to divide the experimental dataset into independent training and test set. We report accuracy (ACC), precision (PREC),

Table 2. Classification performance of different classifiers

	ACC (%)	PREC (%)	REC (%)	F1 (%)
NB	73.32	74.58	71.12	72.81
KNN	74.61	74.43	73.50	73.96
SVM	86.01	85.90	85.57	85.73
C4.5	89.64	89.56	89.32	89.44
LDA	84.46	84.16	84.33	84.24
QDA	74.09	73.88	72.97	73.42
ADA	71.24	74.19	68.26	71.10
SUB	89.38	89.11	89.44	89.27
RF	**92.49**	**92.51**	**92.19**	**92.35**

recall (REC), and F1 [7]. The final values of the four metrics are the mean of the three-fold results. Table 2 presents the experimental results. We can observe that the random forest model outperforms the other eight competitors and obtains an accuracy of 92.49%, demonstrating the power of quantitative gait analysis in the early detection of Parkinson's disease.

To have better insight into the PD detection problem, we show the confusion matrix of three representative classifiers. Tables 3-5 show the results of Naïve bayes, support vector machine, and random forest, respectively. According to the results, we see that random forest achieves satisfactory performance and it only mistakenly classifies 17 PDs into healthy subjects and 12 healthy subjects into PDs.

Furthermore, we investigate the impact of the number of trees on the performance of random forest. Fig. 2 presents the results. The x-axis indicates the number of trees and the y-axis corresponds to accuracy or F1. We can see that using 50 trees is a better choice in obtaining a high accuracy and F1.

Table 3. Confusion matrix of Naïve Bayes

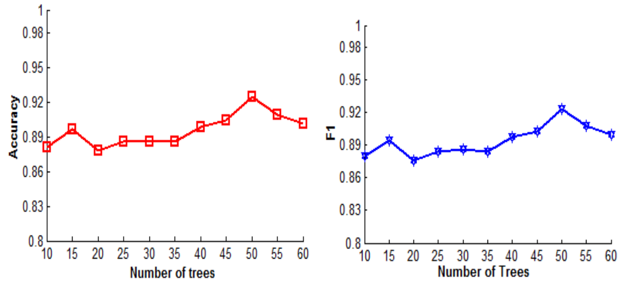
Predicted class	True class	
	PD	Healthy
PD	91	26
Healthy	77	192

Table 4. Confusion matrix of support vector machine

Predicted class	True class	
	PD	Healthy
PD	138	24
Healthy	30	194

Table 5. Confusion matrix of random forest

Predicted class	True class	
	PD	Healthy
PD	151	12
Healthy	17	206



(a) Accuracy (b) F1

Figure 2. Parameter sensitivity analysis

IV. Conclusions

Gait analysis aims to study human motion and its potential association with chronic diseases by extracting various gait characteristics. In this study, we introduce a gait sensing platform that can capture human movement and classify patients with Parkinson's disease from healthy subjects. We collected experimental data from 386 volunteers and conducted experiments to show the possibility of classifying Parkinson's disease patients. Experimental results show that gait-based Parkinson's disease detection remains promising.

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