Gait detection from three dimensional acceleration signals of ankles for the patients with Parkinson's disease

Jonghee Han, Hyo Sun Jeon, Beom Suk Jeon, Kwang Suk Park

Abstract— **Most patients with Parkinson's disease (PD) have gait disorders. Gait monitoring can be helpful in the understanding of the disease advancing state which is useful information for the treatments. Gait detection is the basis of gait analysis. In this study, we designed the general algorithm of gait detection in 3 dimensional accelerations of ankles. The wearable activity monitoring system (W-AMS) was used to monitor the acceleration. 5 normal persons and 5 PD patients had a walking test on the level ground for 6.5m. The foot pressure and movement image were simultaneously recorded for the reference of gait detection. Detection accuracies were 93%, 94% for normal and PD gaits. W-AMS can be attached easily and doesn't interfere with daily activity. Combined with the developed algorithm, it shows a promise of long-term gait monitoring.**

I. Introduction

Gait is defined as a cyclic movement of the feet in which one or the other alternate in contact with the ground [1][2]. Two essentials of gait are equilibrium and locomotion, which are impaired in abnormal gait. Gait analysis has been used to assess the abnormality of gait in patients with movement disorders. Early, primitive apparatuses such as a stop-watch and a ruler were used for gait analysis by measuring walking speed, stride length and variance of these factors. Modern study utilizes a video imaging system monitoring and tracking movements of markers put on several parts of the body. The video system is highly accurate and provides a lot of gait parameters. However, it has temporal and spatial restrictions that limit gait analysis to a specific time and a confined location. In order to monitor a gait at any time and at anywhere, several studies have been conducted on an ambulatory gait monitoring system using tiny motion sensors such as an accelerometer, gyroscope and so on [1][2][3]. The gait of a patient wearing the ambulatory system can be monitored in a whole day. In the field of this research, the extraction of gait parameters from signals measured by motion sensors is the main subject investigated [6].

Patients with Parkinson's disease (PD) have movement disorders which can benefit from gait analysis. In PD, gait disorders such as slowness (bradykinesia), cessation of movement (akinesia) or freezing of gait appear. As the disease advances, these gait disorders become more pronounced, disabling the patients and severely limiting their quality of life [4][5]. To treat the PD patient, the brain surgery or drug treatment is used. Currently, the drug therapy is predominant but the number of the brain surgery is increasing. With the drug therapy, movement condition differs according to the level of medication in the system. In addition, reaction to the medicine is diverse for the person and the state of disease. Because of this, gait analysis conducted with the video imaging system cannot accurately describe the condition of the PD patients. Therefore, the gait of the PD patient needs to be monitored continuously and an ambulatory gait monitoring system is suitable for this requirement.

A gait is a periodic movement and can be decomposed to a single gait cycle. Each gait cycle consists of the stance and swing phase. The stance phase is about 60% of the gait cycle and can be subdivided into the double-leg and single-leg stance [3]. The swing phase consists of three phases: initial swing where the leg is accelerated, mid-swing and terminal-swing where the leg is decelerated. When motion detection sensors are used for the measurement of the gait signal, discernable vertical and horizontal peaks are observed in swing phase. Based on this observation, studies on gait detection were conducted with various motions detecting sensors and showed the promise as an ambulatory gait monitoring system.

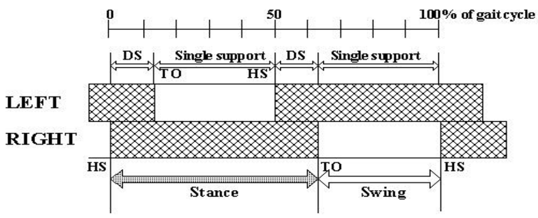

Figure 1. Subphase of one gait cycle. There are the stance phase, which is a checked region, from heel strike (HS) to toe off (TO) and the swing phase, which is an empty region, from TO to HS. Double support (DS) exists when both of two feet are contact with the ground.

This study, as a part of gait detection, constructed a wearable activity monitoring system (W-AMS) measuring accelerations of both ankles and developed the automatic gait

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detection algorithm from the gait signals. Some studies on the automatic gait detection for normal gait were carried out previously [7][8]. However, general gait characteristics were frequently missing in the severe PD patients and sometimes there were noisy peaks similar to the prominent gait peak of the swing phase. For this reason, it was difficult to detect a gait steadily in the case of the PD patients. This study implements a general algorithm of automatic gait detection for both normal and PD gait.

II. Methods

A. *Subjects*

5 normal persons and 5 PD patients were involved in the walking test performed on the level ground for a distance of about 6.5m. Most of the patients showed bradykinesia and akinesia.

B. *Synchronized motion acquisition system*

To measure accelerations of both ankles during walking, we developed a W-AMS measuring three dimensional accelerations (X: horizontal, Y: vertical, Z: transverse) (Fig. 2). It consists of one control board and two sensor modules. The control board containing microcontroller, flash memory and RS232 module is attached to the waist. Each sensor module made of two dual-axis accelerometers is put on the each ankle. The foot pressure system (Fedar-X, Novel, Germany) and the camcorder (DCR-DVD200, Sony, Japan) were used for the reference system. The W-AMS, foot pressure system and camcorder could be controlled and synchronized in the developed software.

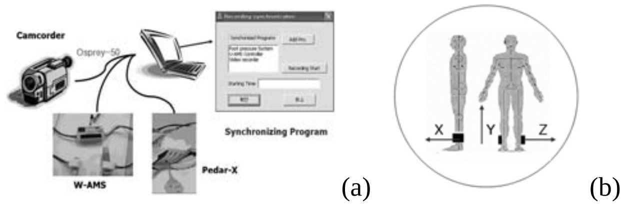

Figure 2. (a) Synchronized motion acquisition system: Camcorder and W-AMS are connected to laptop computer with wire. Pedar-X is connected with wireless bluethooth. The developed synchronizing program starts three motion acquisition systems at once. (b) W-AMS attachment to both ankles: X, Y and Z are three axes of sensors and equivalent to horizontal, vertical and transverse direction respectively.

C. *Characteristics in the acceleration signal of the ankle*

Normally, acceleration signal of a single cycle gait shows characteristic peaks. In the X-axis, there is a smooth positive peak in swing phase and a sharp positive peak next to toe off. In the Y-axis, there are a smooth positive peak in swing phase and some positive peaks near toe-off event. However, abnormal gait sometimes shows peaks with different characteristics. The minimum condition for the gait is that locomotion is always in existence. Among gait characteristic peaks, a vertical positive peak and a horizontal positive peak in swing phase should be present.

D. *Gait detection algorithm*

For automatic gait detection, the gait signal was processed sequentially (Fig. 4). First, moving and stopping blocks were distinguished. Second, stance phase and swing phase were classified in the moving blocks. Third, positive peaks of X and Y acceleration were searched for in the swing phase. Finally, non-gait peaks among the found peaks were removed to detect real gaits. Each part of algorithm will be explained in more detail.

1) Stopping and moving discrimination: Gait signal was divided into segments by 1 second. In each segment, standard deviations of three dimensional accelerations were calculated and compared with a stopping threshold (Tst). The Tst was chosen to be a fifth standard deviation of total signal. If more than three consecutive segments had lower value than Tst, those were classified to stopping periods. The other segments were classified to moving

2) Stance and swing phase discrimination: In moving blocks, gait signals were divided into subsegments by 0.1 seconds. If more than two consecutive subsegments had lower value than Tst, those are determined to stance phase. The other subsegments were determined to swing phase.

3) Positive peak detection: Simple peak detection method was used in the detected swing phase. Among many detected peaks, peaks shown in vertical and horizontal acceleration signal simultaneously were selected.

4) Removal of non-gait peak: In the selected peaks, if the amplitude of a peak is lower than Tst or the shapes of X and Y accelerations near a peak are different, those peaks are removed. In the remained peaks, if the interval of two consecutive peaks is less than 0.5 second, one of two peaks is removed selectively. At last, the remained peaks not removed by the above rules are determined to the gait peaks.

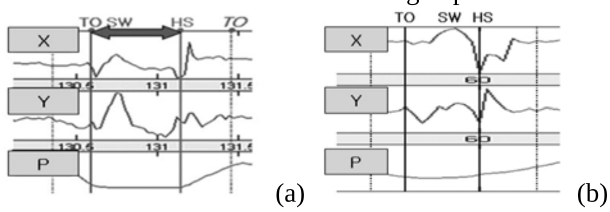

Figure 3. Characteristic peaks of X and Y accelerations in the swing phase. P is the mean value of foot pressure. (a): normal person, (b): PD patient

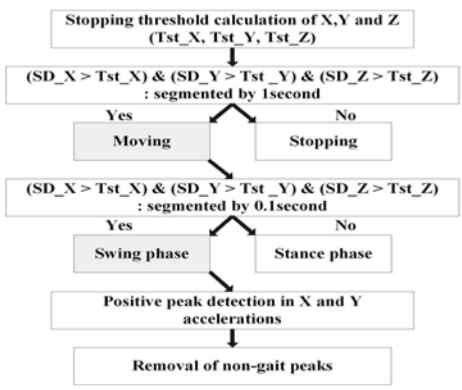

Figure 4. Flow chart of gait detection algorithm. SD_X (Y, Z) means the standard deviation of X (Y, Z) acceleration signal.

III. RESULT

A. Synchronized gait signal acquisition

Foot pressure, three dimensional accelerations of ankles and video recorded image were acquired synchronously. Figure 5 shows the whole results displayed by the developed software. All the signals were exactly synchronized and could be compared with ease.

B. Gait detection results

By examining foot pressure and video image, we marked gait peaks manually. The peaks detected by automatic algorithm were compared with this manual method. In normal persons, the average of gaits was 50 gaits in which 47 gaits were detected rightly. Averagely 2.4 gaits were non-gaits which is the false positives. In PD patients, the average of gaits was 125 gaits in which 116 gaits were detected rightly. Averagely 2.2 gaits were non-gaits which is the false positives.

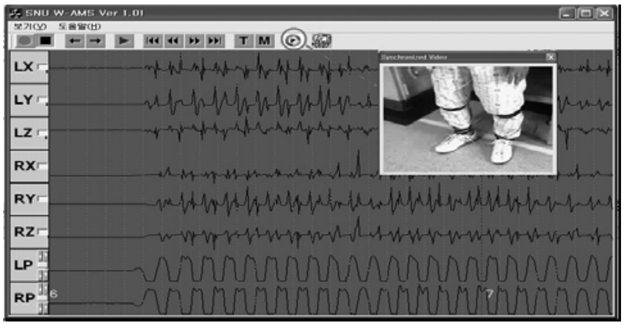

Figure 5. Whole signals acquired from walking test. 'L' ('R') means left (right) leg. Accelerations, foot pressure and video image could be compared synchronously.

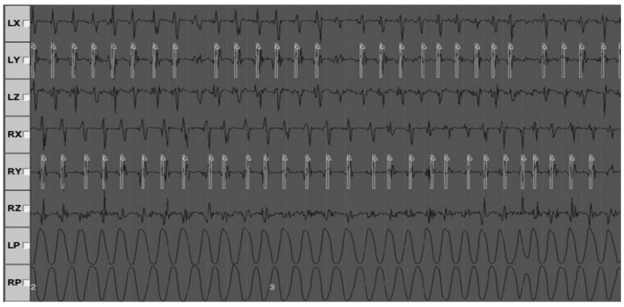

Figure 6. Gait detection result. The thin box marked by 'G' is the automatically detected gait.

IV. DISCUSSION

The present study implemented the automatic gait detection algorithm good for PD gait as well as normal gait. Previous studies considered heel contact as a prominent point for gait detection because at that point the acceleration shows the biggest peak. However, PD patients had unusual gaits: toe-walking, slowness and freezing gait. In these cases, gait signals show different patterns of gait peaks. As shown in figure 3(b), very small peak appeared at the time of heel contact in a PD patient. In order to manage all the circumstance, we developed a general gait detection algorithm. The algorithm was originated from the fact that there happens always locomotion producing acceleration peaks for accomplishing a gait. According to this, we found out gait peaks in the swing phase and removed wrong-detected gaits by the rule suggested in 2.4.4. The results show the detection accuracies of 94%, 93% for normal and PD gait. Validation of the results was conducted by checking the foot pressure and video image synchronously.

This study was performed as a part of constructing a tiny ambulatory activity monitoring system for PD patients. The sensor used in this system is a three-dimensional accelerometer, which is tiny and provides useful kinetic information. If only the gait detection is needed, other sensors could be superior to the accelerometer. But the final purpose of this study was to extract all the useful information from the acceleration signal and the gait detection was one of these procedures.

In the swing phase, positive peaks of X and Y acceleration appear concurrently. This is satisfied when X axis is parallel to the walking direction. If the sensor is attached askew to the walking direction, there is difference between positions of gait peaks of X and Y acceleration [8]. In the most experiments, the sensor is arranged according to the walking direction. However, some people turn their toes out in walking and the sensor is attached askew to the walking direction in some case. Therefore, compensation of phase shift due to wrong arrangement of sensors should be done in next study.

V. CONCLUSION

Gait detection is the primary and essential step for gait analysis. We constructed the general gait detection algorithm in 3 dimensional accelerations of ankles. This algorithm met the accuracy rate in both normal and PD gait. From the detection result, kinetic data such as speed, balance and so on can be extracted. In future study, long-term gait monitoring will be performed with the W-AMS. Gait analysis for pathological gaits will also be carried out. Final goal of the study is to construct the unconstrained gait monitoring system which assesses daily gait characteristics.

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