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Development of a balance analysis system for early diagnosis of Parkinson's disease

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A R T I C L E I N F O

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A B S T R A C T

The purpose of this research is to develop a postural balance evaluation system using center-of-pressure (COP) analysis techniques for early diagnosis of Parkinson's disease (PD). A COP sensing device was developed, and applicable test protocols were proposed. Subsequently, posturographic parameters, which reflect the characteristics of postural control, were extracted to evaluate postural balance. Decisive indicators for postural stability were selected among the posturographic parameters through statistical validation based on clinical data. A discriminant function was then suggested to predict the existence of PD in patients. This clinical study consisted of 127 participating subjects. A validation study ($n = 51$, 40% of the overall data) using the discriminant function concluded with 100% accuracy that 37 healthy subjects did not have PD and 14 subjects with PD were correctly diagnosed.

Relevance to industry: Postural instability has become a critical issue since people with postural balance disorders are frequently exposed to the danger of falling and injuries. This paper provides a device, test protocol, and evaluation method to analyze postural balance and predict the existence of PD. We expect that our proposed system can be exploited for neurosurgery of PD patients, and other clinical medical fields such as rehabilitation, geriatrics, and orthopedics.

1. Introduction

Human posture involves the alignment of body segments within the surrounding environment, and the control of postural alignment is universally called postural balance or equilibrium (Cech and Martin, 2002). Patients who present postural instability, for example, Parkinson's disease (PD), stroke, Ménière's disease, and multiple sclerosis patients, have impaired functioning of their postural control system. Generally, this may be caused by a deficiency in any component of the postural control loop or an interaction of the components. Based on the cause and disease, patients may present different symptoms and/or behaviors. However, these patients can be considered to have postural balance disorders in terms of postural control, and commonly have instabilities or abnormalities in maintaining static postures or performing physical movements. Thus, it may be feasible to diagnose postural balance related diseases and verify the progress of rehabilitation through postural balance evaluation (National Institute, 2010), (Wrong Diagnosis, 2010).

In particular, PD is a common movement disorder that has an estimated worldwide prevalence of 6.3 million people (Clarke, 2007). The cause of PD is progressive impairment or deterioration of the neurons in the substantia nigra area of the brain. PD patients have motor related symptoms such as tremors, rigidity, slowness of movement, and postural instability. Diagnosis of PD is based on movement symptoms (tremors, bradykinesia, rigidity, loss of balance, etc.), non-movement symptoms (dementia, depression, psychosis, anxiety, falls, etc.), physical examination (questionnaires, overall health checks, simple testing procedures, etc.), and tests to eliminate other possible diagnoses (scans-SPECT, MRI, PET, etc.) (National Collaborating). However, there is no specific method to diagnose PD through postural balance evaluation despite the fact that postural balance is an important factor in diagnosis. Therefore, it is necessary to develop a system to diagnose PD through postural balance evaluation.

Research of postural balance evaluation has been performed using various methods to quantify balance capabilities. However,

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there is no single evaluation technique that is a true indicator of the overall integrity of the postural control system; therefore, the selection of a suitable method generally depends on the desired goals and results (Winter, 1990). Typical approaches for postural balance evaluation and diagnosis include body motion analysis, performance-based assessments, electromyogram (EMG) analysis, and COP-based body sway analysis (Winter, 1990).

COP analysis utilizes a force platform and is one of the most popular techniques because of its relative simplicity, short measurement time, and small size system for installation (Lin et al., 2008). The basic principle of the force platform test is to measure the movements of the COP that reflect both the horizontal location of the center-of-gravity (COG) and the reaction forces due to muscular activity (Era et al., 1996). Compared to other methods, COP-based postural analysis has additional advantages for postural balance evaluation: it reflects tiny movements and detects possible postural imbalance or instability. Also, test protocols and COP analysis parameters can be standardized, thereby making it highly applicable for different types of studies. It is also extendable to various test protocols, so the cause of postural imbalance can be found through comparative analysis between the results obtained using different test protocols.

Although there are various postural balance evaluation systems that use the COP method, they are typically expensive, exclusively measure body balance, and lack the diagnostic applications to evaluate postural balance disorders such as PD. Most existing systems are hard to understand and meaningful results are difficult to generate. Therefore, this study aims to develop a system using COP analysis that enables the evaluation of postural balance and prediction of PD.

2. Methods

2.1. Posturography device development

To develop a COP variation measurement system for postural sway analysis, a force platform device is required. The force platform device has three components: a foot platform supporting the subject's body and transferring force variation from the subject to the sensors, sensors detecting force variation, and a hardware module to process analog/digital force signals and transmit them to the computer.

2.1.1. Sensor and foot platform

Four high precision load-cell sensors (Bong-Shin, 2010) corresponding to the subject's left-foot-front, left-foot-rear, right-foot-front, and right-foot-rear are utilized for accurate measurement of the force variation. Theoretically, the load-cell sensors for our device can measure up to 150 kg of force, and have a maximum error of 30 g. The output voltage is 2 mV when 1 V is supplied and 150 kg of external force is applied. The foot platform for supporting the subject's body was designed to cause no loss of force or force interference between the sensors (see: Fig. 1).

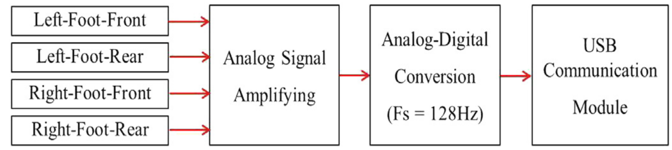


Fig. 2. Flow process of posturography hardware module device.

2.1.2. Hardware module

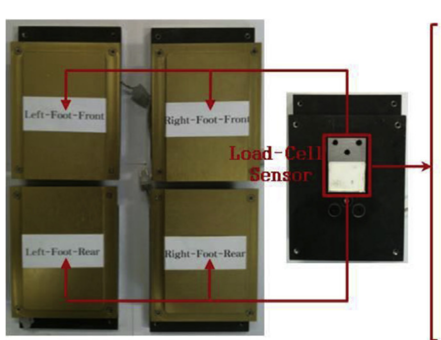
Analog signals from each sensor are independently amplified by an instrumental amplifier (AD623) (Analog Device, 2010), filtered by an operational amplifier (TL072) (Texas Instruments – TL072, 2010), and transmitted to analog followed by an analog to digital converter (ADC). A microcontroller (MSP430FG437) (Texas Instruments – MSP430FG437, 2010) for the main controller and a sub-controller (AT90USB162) (ATMEL, 2010) for USB communication are used for digital signal processing (see: Fig. 2).

MSP430FG437 supports a 12 bit-ADC, timer, electrically erasable programmable read-only memory (EEPROM) and RS232 serial communication, etc. Transmitted signals from an analog circuit are converted to digital signals with a sampling frequency (fs) of 128 Hz by an ADC with a timer trigger. Converted digital signals are transmitted to the sub-controller by RS232 serial communication, and are transmitted from the sub-controller to the computer by USB communication. The complete hardware module and device are depicted in Fig. 3.

2.1.3. Performance verification

Experimental comparison between known and measured weights was performed for accuracy verification. Twenty-three precise balance weights (500 g, 1 kg, 2 kg, 5 kg, 10 kg, 15 kg, 20 kg, 25 kg, 30 kg, 35 kg, 40 kg, 45 kg, 50 kg, 55 kg, 60 kg, 65 kg, 70 kg, 75 kg, 80 kg, 85 kg, 90 kg, 95 kg, and 100 kg) were used for experimental comparison. Each weight was randomly put on the foot platform, and the measured weight was recorded in the local database.

Each of the balance weights was measured repetitively 100 times, and the experimental procedure was performed for three months. After completing the procedure 100 times, the correlation between the known weights, measured weights, and errors was analyzed using the recorded data.



Model	YZC-171
Capacity	150 kg
Output Sensitivity	2.0±0.1 mV/V
Nonlinearity	0.02 %
Repeatability	0.02 %
Hysteresis	0.01 %

Fig. 1. Foot-platform with four load cell sensors and its specification.