

## BIO-DYNAMIC ANALYSIS OF WALKING USING GYRO SENSOR SYSTEM

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### ABSTRACT

This study presents a newly developed simple and cordless system, that consists of a gyro sensor and is connected to a small easily wearable personal computer (WPC) of a wrist watch type. The lithium rechargeable batteries are supplied as electrical power of a gyro sensor. While walking, the WPC is worn like a wrist watch, the small sensor is fixed to a patient's back near the center of body gravity, and batteries are inserted into a patient's waist pouch. When a switch is turned on, the serial time count, relative three angles, i.e., roll, pitch and yaw meterage, and accelerations in X,Y,Z axis of the patient's back are recorded into WPC at 30 Hz. In this study, patients who wear complete denture were selected as subjects in Hospital. In order to analyze walking stability, this study presents power spectral analysis utilizing auto regressive modeling. In case of patients not wearing denture, the power spectrum densities of the three angles and accelerations of back fluctuation were wavy, i.e., it is unstable walking in roll, pitch and yaw direction. In case of patients wearing denture, their power spectrum densities were approximately close to  $f^{-3}$  ( $f$ : frequency) fluctuation, i.e., it is stable walking in all direction. It is well known that the  $f^{-3}$  appears in stable and normal biological phenomenon. Not only our developed system provides us useful information for analyzing of walking stability, but also everyone can find out their walking stability easily in rehabilitation and physical fitness.

### 1 INTRODUCTION

The CCD video cameras are used for the 3-D measurement of walking movement. However, there are some problems: the measured distance is not enough for the walking analysis because cameras are fixed at place, and it is necessary to process many images (Tsuruoka, et al. 1996, 1997). The gyro sensor is used for a real-time measurement of relative three angles, i.e., roll, pitch and yaw meterage, and accelerations in X, Y, Z axis simultaneously. Also there are some problems: long cords are necessary from AC supply and computer to a patient. Furthermore, a patient is required to walk on a moving treadmill. In rehabilitation, it is expected to measure without cords and to secure some extent of the walking distance and the going up-down stairs in daily movement for medical evaluation.

This study provides a newly useful gyro sensor system for Walking (Figure 1). When a switch is turned on, the serial time count, relative three angles, i.e., roll, pitch and yaw meterage, accelerations in X, Y, Z axis of the patient's back are recorded into WPC at 30 Hz. They are also displayed on a liquid crystal display on the WPC. It was observed that each angles and accelerations of walking by wearing dentures had better rhythm. But, it was difficult to explain

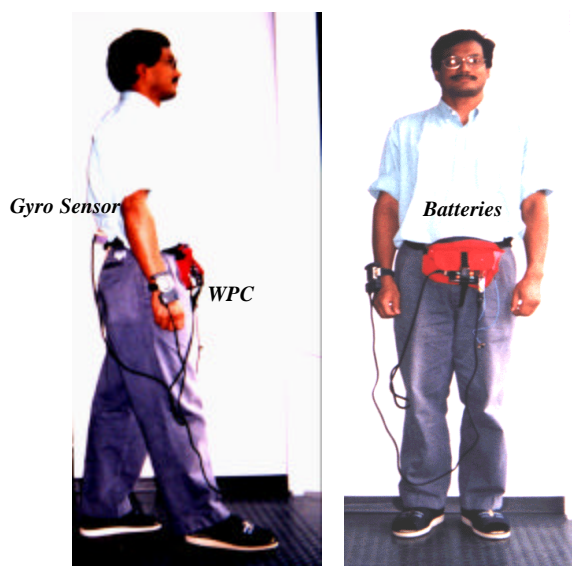


Figure 1 Gyro Sensor System for Walking Analysis

the difference of every patient's feature by original data. In order to analyze walking stability, this study presents power spectral analysis utilizing auto regressive modeling. In case of patients not wearing denture, it was observed the power spectrum densities of the three angles and accelerations of back fluctuation were wavy, i.e., it is unstable walking in roll, pitch and yaw direction. In case of people wearing dentures, it was observed that their power spectrum densities were approximately close to  $f^{-3}$  ( $f$ : frequency) fluctuation, i.e., it is stable walking. Finding the  $f^{-3}$  in walking movement expresses one of indexes for walking stability. Using our developed system, everyone can find out their walking stability easily by simple operating and cordless in rehabilitation and physical fitness.

## 2 METHODS

### 2.1 Gyro Sensor System

The Gyro Sensor System is consisting of a MAXCUBE gyro sensor and a small wearable personal computer (WPC) of a wrist watch type (Figure 2). The output of roll and pitch angle is limited in  $\pm 180^\circ$ , pitch angle is limited in  $\pm 90^\circ$ . The output of XYZ accelerations are limited in 2G ( $G=9.8 \text{ m/sec}^2$ ). The accuracy of each angle measurement is under  $0.2^\circ$ , and its acceleration is under 0.01 G. When a switch is turned on, the calibration of MAXCUBE gyro sensor starts before measurement. After 10 minutes, an end sign appears, the measurement starts by pushing a button of WPC. The degrees of angles and accelerations become  $0^\circ$  just after calibration and the serial time count, their relative data are acquired. When a switch is turned on, the serial time count, relative three angles, i.e., roll, pitch and yaw meterage, accelerations in X, Y, Z axis of the patient's back are recorded into WPC at 30 Hz. They are also displayed on a liquid crystal display on the WPC. The lithium rechargeable batteries are used as power supply for the gyro sensor. The long cords are not necessary from AC supply and computer to the person.

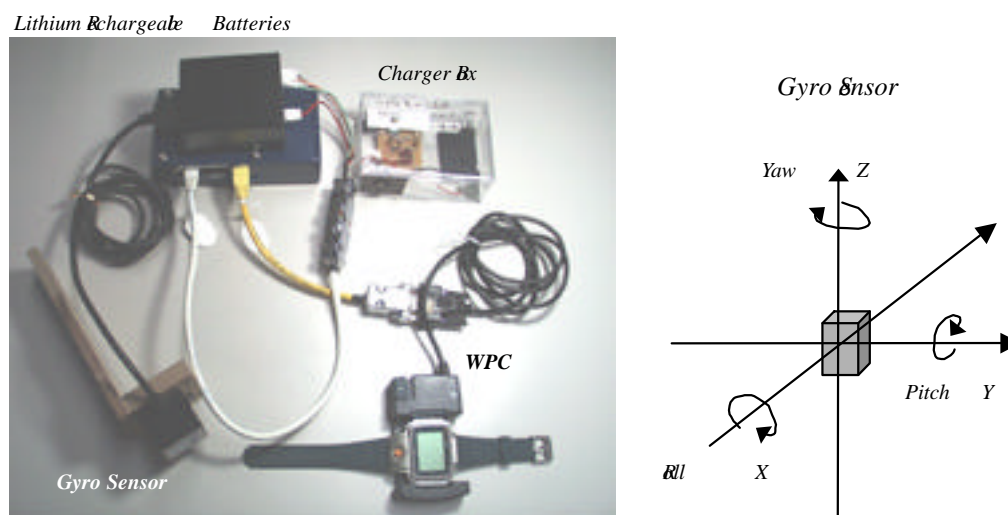


Figure 2 Gyro Sensor System

### 2.2 Spectral Analysis Utilizing Auto Regressive (AR) Modeling

A stationary time series is given by the portion that can be expressed as a linear combination of  $M$  past values and the series of residuals, i.e., white noise. Univariate AR modeling is given as follows (Kitagawa, 1996):

$$x(s) = \sum_{m=1}^M a(m)x(s-m) + u(s) \quad (1)$$

where,

$x(s)$ : stationary time series,  $x(s-m)$ : past observed data,

$u(s)$ : white noise,  $a(m)$ : AR coefficient.

Power spectral density: The estimate of the power spectral density  $p(f)$  is given by

$$p(f) = \frac{\mathbf{s}^2(M)}{\left| 1 - \sum_{m=1}^M a(m) e^{-i2\pi f m} \right|^2} \quad (2)$$

where,

$\sigma^2(M)$ : auto-covariance,  $e^{-i2\pi f m}$ : Fourier transform of frequency response.

This formula defines the best prediction, giving the power spectral density, which expresses the characteristics of a sequential system concisely, decomposing it into periodic components

### 3 RESULTS & DISCUSSION

#### 3.1 Bio-mechanical Analysis of Walking

**3.1.1 Displacement of patient's back who wears denture in walking.** In this study, patients who wear complete dentures were selected as subjects (Figure 3). Twenty patients were between 70 to 85 years old. They were measured for two types walking using the Gyro Sensor System during ten minutes on straight line in the Hospital. The one type was for analysis of walking by patients wearing dentures, another one was for analysis of patients not wearing dentures. All patients walked naturally, their own speed. The original data, i.e., the serial data of relative three angles, i.e., roll, pitch and yaw, meterage and three accelerations in X, Y, Z axis, of patients back were recorded at 30 Hz using the Gyro Sensor System. While walking, the gyro sensor is fixed to a patient's back near COG. The back displacement of patient was analyzed as a bio-mechanical analysis.

In case of patients not wearing dentures, it was observed the displacements of the roll, pitch, yaw angles and accelerations in X,Y, Z axis of back fluctuation were not rhythmic, i.e., it looks unstable walking (Figure 4 left). In case of patients wearing dentures, it was observed the displacements of the roll, pitch, yaw angles and accelerations in X,Y, Z axis of back fluctuation were better rhythmic, i.e., it looks stable walking (Figure 4 right). It is found that the complete dentures have tendency to control better walking as well as chewing foods. But, it was difficult to explain the difference of every patient's feature by original data.,

#### 3.2. Spectral Analysis of Walking

Most of medical doctors used to understand from their clinical experiences. That is, the diagnoses of medical problems depend on their experiments. Also the serial measurement data were difficult to analyze directly the characteristics of movement stability, because of their complex fluctuations in feedback control movement among their variables.

**3.2.1 Power Spectrum of patient's back who wears denture in walking.** In case of patients, who were not wearing dentures, their power spectrum densities of the back fluctuations of three angles in walking are wavy. But in case of patients who wear dentures, their power spectrum densities of the back fluctuations of three angles improved close to  $1/f^3$  (f: frequency) fluctuation, i.e., it is stable walking in all direction.

**3.2.2 Power Spectrum of normal person's back who had experienced damage in orthopedics.** The test data were obtained from four persons: Person A has suffered a pelvic fracture, the person B has suffered a foot fracture, the person C has suffered a lumbar disk herniation and the person D has suffered nothing, normal. They are in their twenties. In case of person A, B, C, the power spectrum densities of each back fluctuations of three accelerations in walking are wavy. But, in case of normal, it also observed that the power spectrum densities of the back fluctuations of three accelerations in walking are



Figure 3 Denture (above) & Patient (below)

close to  $1/f^3$  fluctuation (Figure 6).

## CONCLUSIONS

The stability of COG suggested the stability of human movement balance and also the power spectral analysis utilizing AR modeling provides clear results of the medical evaluation for human movement. It was said that the power spectral analysis expressed characteristics of sequential system decomposing into periodic components. This developed simple gyro sensor and useful analyzer system for human movement stability provides more diverse, new medical evaluation and indexes for improvement in rehabilitation and physical fitness.

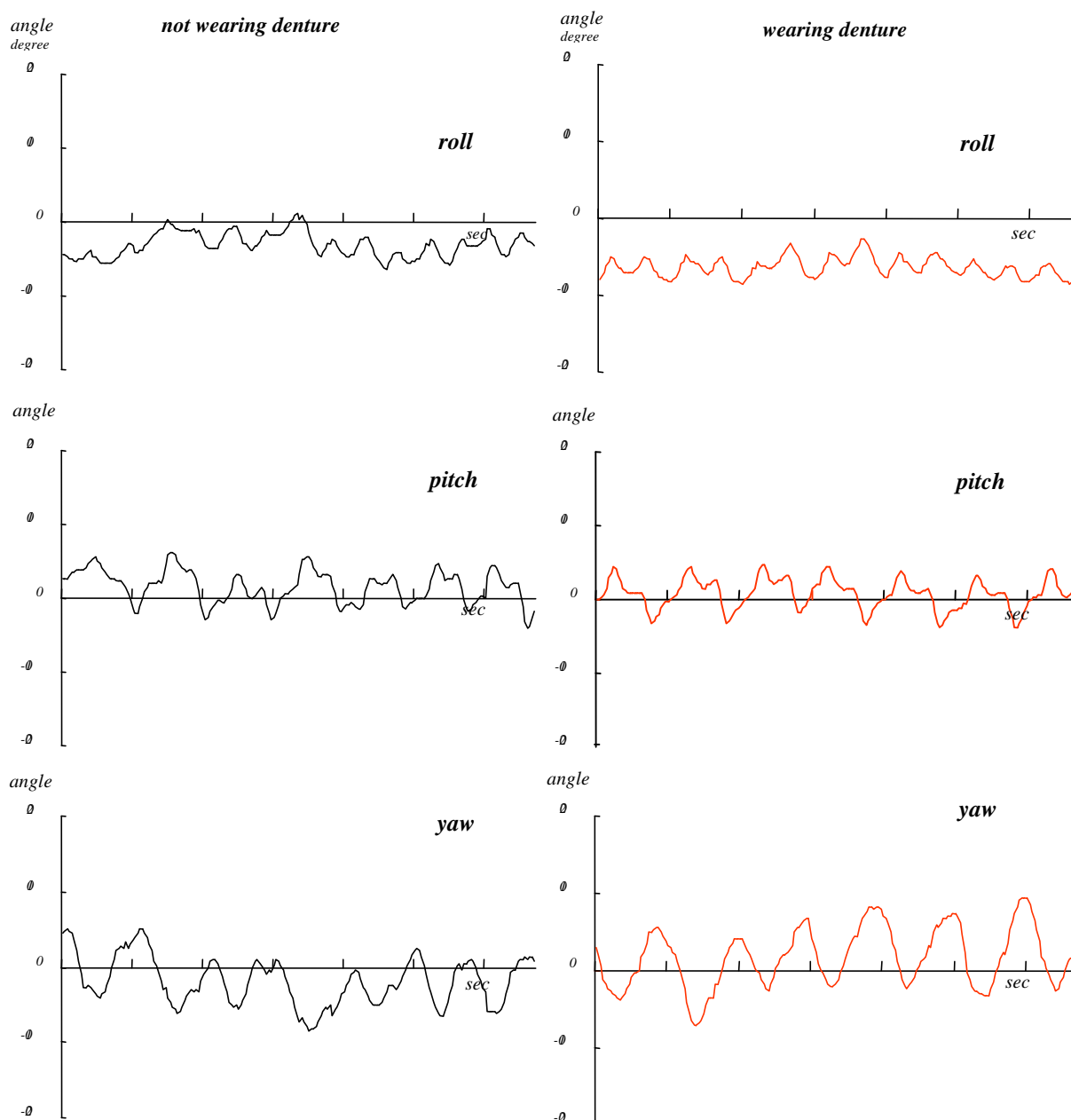


Figure 4 Displacement of three angles in walking (Patient wearing denture between 70 to 85 years old) old)

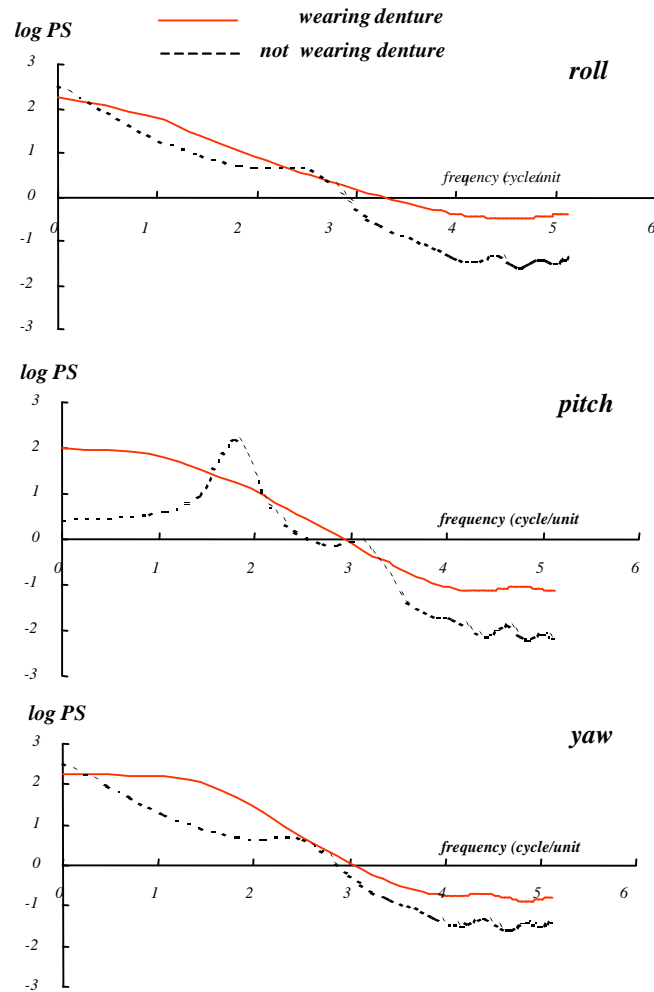


Figure 5 Power Spectrum of three angles in walking (Patient wearing denture)

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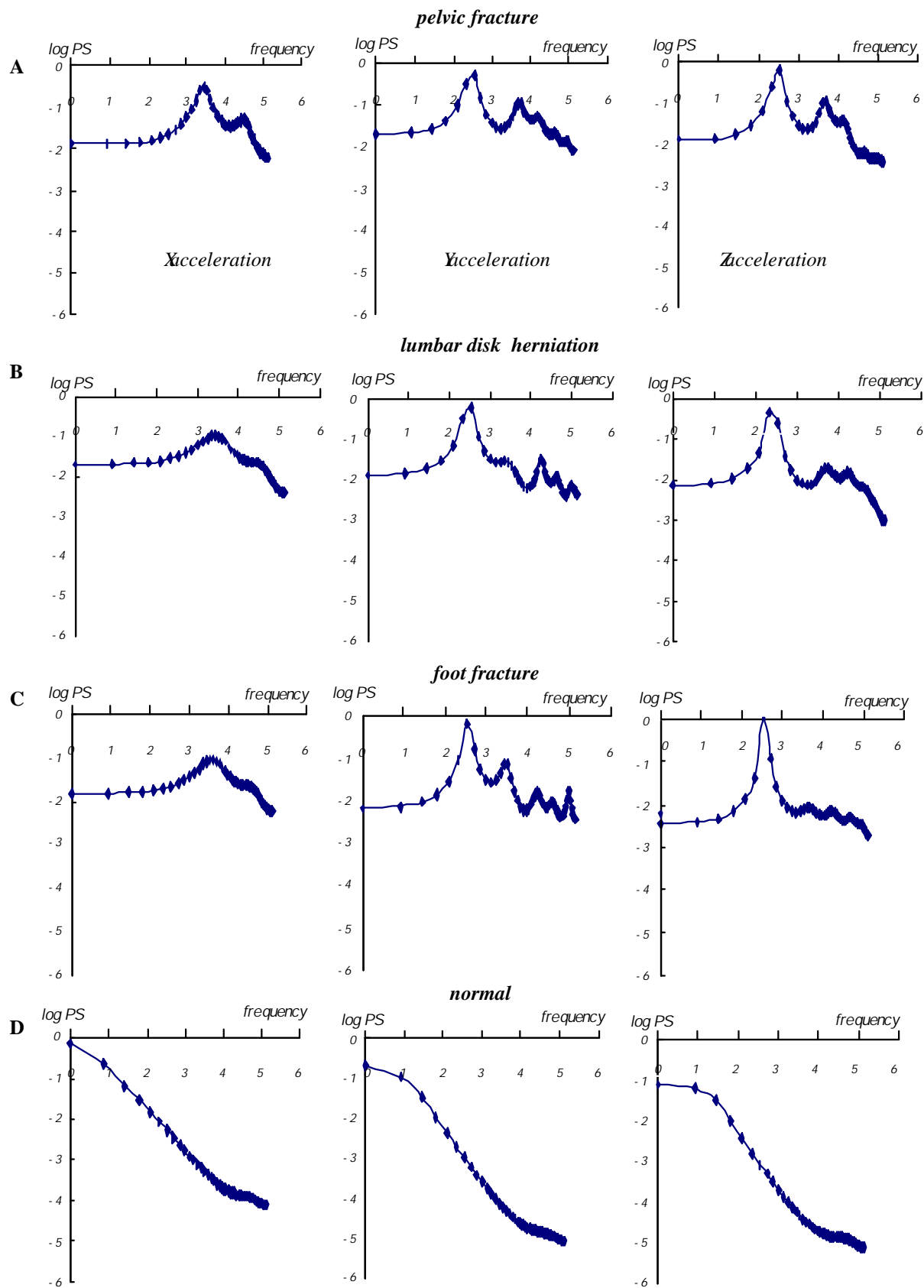


Figure 6 Power Spectrum of three accelerations in walking (Persons having experienced damages in orthopedics vs Normal )