# Automatic Step Detection in the Accelerometer Signal

H. Ying[1], C. Silex [1], A. Schnitzer[1], S. Leonhardt[2], and M. Schiek[1]

[1] Central Institute for Electronics, Research Centre Jülich, Germany
[2] Philips Chair for Medical Information Technology, RWTH Aachen University, Germany

*Abstract*— **The automatic step detection is a crucial component for the analysis of vegetative locomotor coordination during monitoring the patients with Parkinson's disease. It is aimed to develop the algorithms for automatic step detection in the accelerometer signal, which will be integrated in sensor networks for neurological rehabilitation research. In this paper, three algorithms (Pan-Tompkins method, template matching method and peak detection based on combined dual-axial signals) are detailed described. Finally, these methods will be discussed by means of dis- and advantages.**

*Keywords*— **Step detection, accelerometer, Pan-Tompkins method, template-matching method, neurological rehabilitation research**

## I. Introduction

Parkinson's disease (PD) is associated with reduced coordination between respiration and locomotion [1]. For the neurological rehabilitation research, it requires a long-time monitoring system, which enables the online analysis of the patients' vegetative locomotor coordination. The online analysis allows the later integration of bio-feedback protocol for the rehabilitation purpose. This system will facilitate the identification of the therapeutic effect and measuring the patients' health status. To monitor the phase synchronization between respiration and locomotion, the accurate time of step event has to be determined. The commercial pedometers, which count each step a person makes, can not fulfill this requirement. For this purpose, the online algorithm is developed for the automatic step detection. Since the characteristics of the PD patients' gait are pronounced different from the normal gait [2], the database for algorithm development in our work is acquired only from the PD patients.

The first experiment on the locomotion measuring is carried out using accelerometer. The accelerometer signals show considerable difference in morphology and amplitude among the individuals. We attempt to design a fast and robust algorithm, which should be suitable for individual patients, without any user-specified parameters. So far, three methods have been investigated for this project:

- Pan-Tompkins Method
- Template-Matching Method
- Peak-detection method based on combined dual-axial signals.

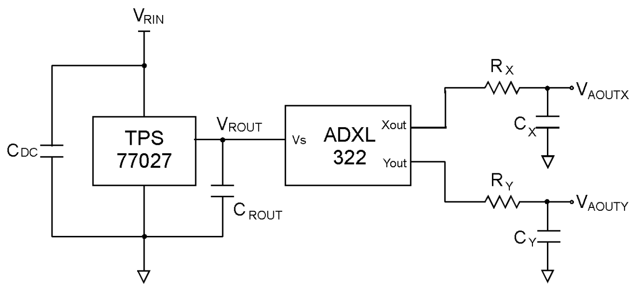
These three algorithms will be described in detail below, as well as their preliminary results on the patients' data. Finally, the dis- and advantages of these methods will be discussed.

## II. Methodology

### A. Subjects and Equipment

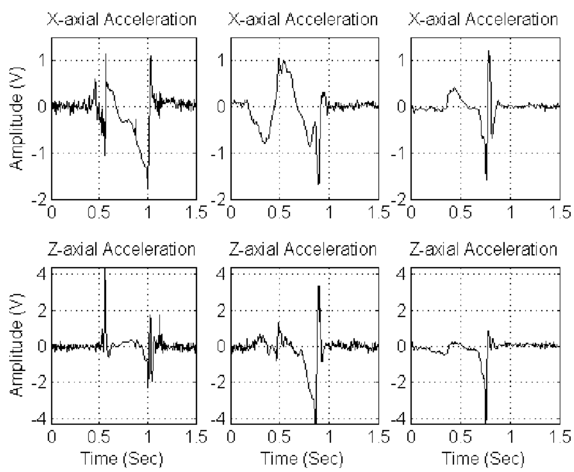
*Subjects:* In total, eight patients suffering from PD were measured in the Clinic Ambrock for Neurology, Centre for Sleep- and Rehabilitation Research, Germany. The patients are at different stage from 1 through 4 according to unified rating scale (UPDRS). To evaluate the algorithms, data in total duration of 115 minutes were collected from eight recordings. They are acquired at a sample rate of 200 Hz. The patients were walking on a treadmill with accelerometers attaching on the lateral side of the left and right feet during the measurement. Meanwhile, the abdominal and thoracic respiration signals were measured and acquired with a sample rate of 20 Hz.

*Equipment:* The horizontal and vertical acceleration in x- and z-axis generated from the locomotion during steps is measured by ADXL322, a low power dual-axis accelerometer, produced by Analog Devices, Inc. The schematic circuit diagram of the accelerometer for activity measuring is provided in Fig.1 below. The accelerometer is supplied by battery voltage through a low-dropout voltage regulator (TPS77027) to maintain constant 2.7 V level. To improve transient response and noise rejection, a 1 $\mu F$ ceramic capacitor ($C_{DC}$) is connected between $V_{RIN}$ and GND. The voltage regulator requires a 4.7 $\mu F$ capacitor ($C_{ROUT}$) connected between $V_{ROUT}$ and GND. The output of regulator is brought into ADXL 322 through pin Vs. The ADXL322 contains two 32 $k\Omega$ resistors ($R_X$ and $R_Y$) in each output inside IC, respectively. The 0.1 $\mu F$ capacitors ($C_X$ and $C_Y$) are added at the pins $X_{OUT}$ and $Y_{OUT}$ to implement passive low-pass filtering of 50Hz, first order, to eliminate high frequent noise. The output signals: $V_{AOUTX}$ and $V_{AOUTY}$ are analog voltages that are proportional to acceleration.




F*ig. 1* Schematic diagram of the accelerometer application circuit

Fig. 2 depicts the acceleration of three patients on the left feet in the horizontal (x-axial) and vertical (z-axial) direction during walking. Each column of figures shows the data of one patient. The morphology of the acceleration, which depends upon the posture and gait of the individuals, shows great difference among the patients. The accelerometer signal on the left foot is similar with the signal on the right foot. Observe from Fig. 2 that normally, one step consists of two positive peaks, which occur when the foot lifts off the ground and heel strikes the ground, respectively. Either of them is the significant feature of steps in the time domain. The peaks of varied amplitude and morphology are attempted to be detected using the following three algorithms.




(a) Patient 1 (b) Patient 2 (c) Patient 3

F*ig. 2* The acceleration signal measured on the left feet of three patients in the horizontal and vertical directions

### *B. Algorithm Overview*

*I Pan-Tompkins method:* Pan and Tompkins proposed a real-time algorithm for detection of R peak in ECG signal [3],[4]. An experiment is made to investigate, whether this algorithm can also be used for step detection in the accelerometer signal. This algorithm includes a series of filters and methods that perform low-pass, derivative, squaring, integration for preprocess and adaptive thresholds for peak-searching. Fig. 3 illustrates the steps of the algorithm in schematic form. And the results of each step processed on a signal segment of 6 s as shown in Fig. (a) are plotted in Fig. 4 (b) through (g) in sequence.


F*ig. 3* Block diagram of the Pan-Tompkins algorithm

**Bandpass-filter:** The bandpass filter reduces the influence of artifacts in the signal. In this work, the highpass filter is not applied. The digital lowpass filters with small integer coefficients are designed for fast execution. The following lowpass filter with a cutoff frequency of 20 Hz was applied:

$$H(z) = \frac{1}{16}\frac{(1-z^{-4})^2}{(1-z^{-1})^2} \qquad (1)$$

**Derivative operator:** The derivative operator is specified as:

$$y(n) = \frac{1}{8}[2x(n) + x(n-1) - x(n-3) - 2x(n-4)] \qquad (2)$$

Note that eqn. (2) approximates the ideal derivative operator up to 30 Hz. Fig. 4 (b) illustrates the effect of the derivative, i.e., to suppress the low-frequency components and enlarge the high frequency components from the high slopes.

**Squaring:** The squaring operation leads to positive result and enhances large values more than small values. As shown in Fig. 4 (c), the squaring operator increases the high-frequency components further.

**Integration:** The output resulted from the preceding operation in Fig 4 (c) exhibits multiple peaks and hence needs to be smoothed. It is smoothed through a moving-window integration filtered:

$$y(n) = \frac{1}{N}[x(n-(N-1)) + \dots \\ x(n-(N-2)) + \cdots + x(n)] \qquad (3)$$

where N is chosen to be 20 empirically. The Fig. 4 (e) depicts the preprocessed signal beneath the original one in Fig 4 (a) for comparison. Each step cycle yields double peaks with monotonic ascend and descend.