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Gait cycle recognition based on wireless inertial sensor network

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Abstract

This paper presents a method of recognizing gait cycle based on Wireless Inertial Sensor network. The wireless inertial sensor network is embedded in shoes with accelerometers and gyroscopes to measure inertial signal during walking. In gait analysis, gait cycle is one of the most important parameters. Based on gait cycle, we can easily calculate the step continuity, step regularity, step symmetry and so on. Especially for lots of diseases estimation, such as Parkinson's disease, the accurate time of step is a very important parameter. The commercial pedometer, which can simply give the counts of gait, cannot give the accurate time of gait cycle. Based on shoes embedded with inertia sensor, we develop one method using peak detection of combined inertia sensor signal. Experimental results show the method has less error and high precision.

Key words: Gait Cycle, Inertia Sensor, Wireless Sensor Network, Extremum Point;

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1. Introduction

Walking may be the most important activities of our daily life. Gait as a biologic character can be used for identity recognized, health monitor, and medical evaluation. So developing cost-effective methods of gait monitor is very useful. If the gait cycle can be calculated in real time, it will be possible to detect and analyse gait characters continually.

Traditionally, lots of methods have be used for gait character detected such as using a stopwatch though measuring step speed, step length, step height and other characters of these factors. In a general way video and photo imaging systems are used for monitoring and tracking movements of human body. Those systems have highly precision and give lots of many other gait characters. But it is very expensive and can only be used in the specifically condition for gait analysis.

There are several studies that have been present about gait analysis based on the system using inertial sensors such as accelerometers, gyroscopes and so on [1,2,3]. Accelerometers and gyroscopes have been also used in many wearable computing systems for behavior classification, fall detection and gait analysis [4]. Many other systems using Accelerometers and gyroscopes are developed for measuring the physics parameters in[5,6].

This paper presents a method and designs a pair of shoes embedded inertial sensors for real-time gait cycle recognition. As a part of gait analysis, a pair of motion monitoring shoes are designed for measuring inertial signal of two feet, and upload the real-time inertial data in wireless to the computer. And we can develop the gait detection algorithm based on the gait inertial signals on PC, to get the gait cycle in real-time. Based on the gait cycle, we can easily give other gait parameters such as step continuity, step regularity, step symmetry, and so on.

2. Hardware system

This section will be dedicated to the inertial sensor network and the way the inertial sensors are set on both feet for gait analysis. The network is composed of two slave sensor nodes and one data receiver node. Each slave node is based on an InvenSense inertial sensor chip MPU-6050 which is the first solution with integrated 6-axis sensor fusion using its field-proven and proprietary fusion engine for consumer electronics applications. The MPU-6050 is an inertial sensor chip embedded 3-axis accelerometer and 3-axis gyroscope [7].

Each slave node also has a microcontroller with RF function. The sensors are connected to the data receiver in wireless. The structure of the system hardware as showed at Fig.1. The accelerometers have selectable sensitivity and range between ±4g that best fits the kind of data to be analyzed, and the gyroscope is ±750°/s. The blue print of the shoes as showed at Fig.2. The direction of inertial sensors is also given.

We embed the PCB, Ceil, and Wireless charge coil into the shoes. And the switch, USB port, LED are fixed at the back of shoes. The prototype of the wearable motion detector shoes are shown at Fig.3.

The data receiver as showed at Fig.4 communicates with PC via USB. All of inertial sensor data is uploaded to a PC via USB port for processing, analysis, recognition. The system collects the inertial signal on each sensor at 50 Hz.

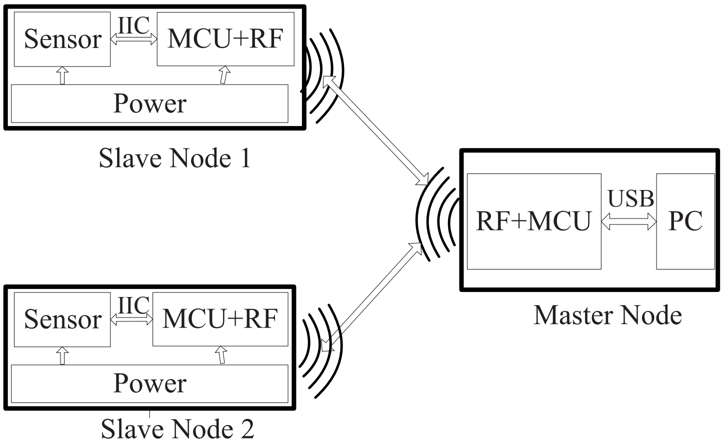


Fig.1.The hardware framework of the wireless inertial sensor network

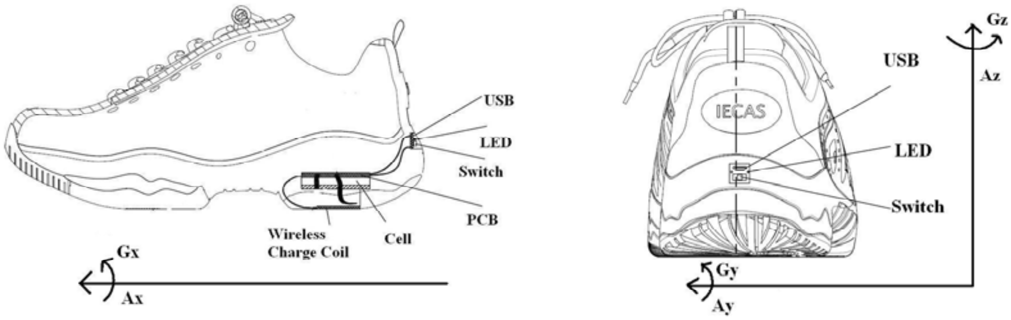


Fig.2.The blue print of the wearable motion detector shoes

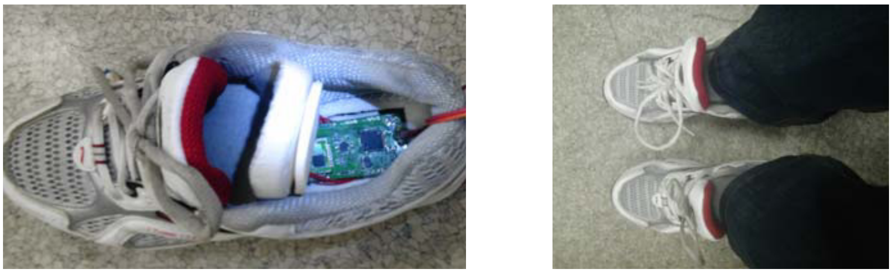


Fig.3.The prototype of the shoes

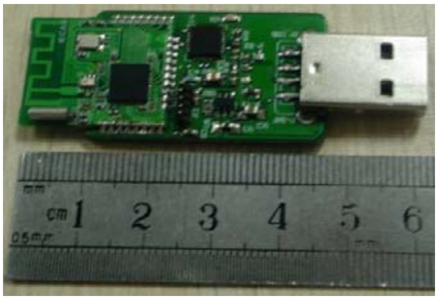


Fig.4.The prototype of the data receiver

3. Algorithm Overview

In slave sensor nodes the 3D accelerometer data is processed by filters in order to decrease the noise. The 3D accelerometer data is also encrypt and transferred to the master in wireless. The master node receives the data and uploads to PC. The data which is transferred to a PC is processed and analyzed in it.

Based on Fig.2 depicted, The X-axis of accelerometers and the Y-axis of gyroscopes are sensitive axis. So we design the algorithm shown in Fig.5 which shows a flow chart of the algorithm. The inertial signal data passes through lowpass filter, Derivation, squaring function, Moving-Win integration, Normalized, and data fusion before thresholds are set and The extremum value are detected[8,9, 10].

The inertial sensor data passes through a lowpass filter in the first step in order to reduce the frequency interference and other noise.

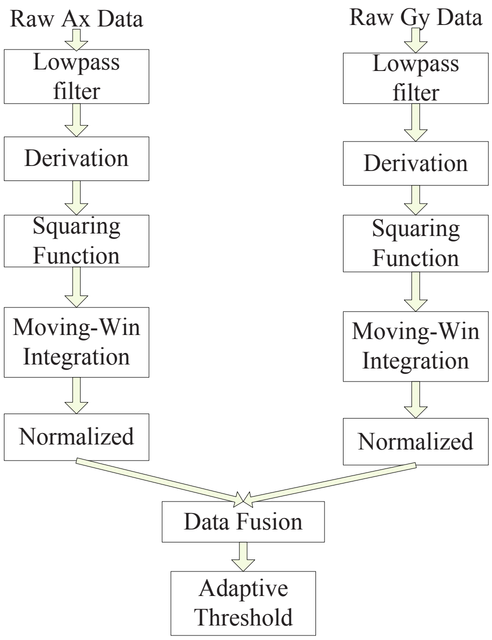


Fig.5. the flow chart of algorithm.

The lowpass filter is described by the formula:

$$H_{LP}(z) = \frac{1 - z^{-6}}{1 - z^{-1}} = 1 + z^{-1} + z^{-2} + z^{-3} + z^{-4} + z^{-5} \tag{1}$$

And the cascade transfer function is:

$$H_{LP}(z) = \frac{1}{32}\left(\frac{1 - z^{-6}}{1 - z^{-1}}\right)^2 \tag{2}$$

The corresponding difference equation is:

$$y[n] = 2y[n-1] - y[n-2] + \frac{1}{32}\left(x[n] - 2x[n-6] + x[n-12]\right) \tag{3}$$

After the lowpass filtering, the signal is differentiated. We use a five points differentiator described by the formula:

$$H_{dif}(z) = 0.125 * \left(2 + z^{-1} - z^{-3} - 2z^{-4}\right) \tag{4}$$

So the difference equation then becomes

$$y[n] = \frac{1}{8}\left(2x[n] + x[n-1] - x[n-3] - 2x[n-4]\right) \tag{5}$$

After differentiation, all of points are squared. The difference equation is described by the formula:

$$y[n] = (x[n])^2 \tag{6}$$

All the data will be positive and the data having a big difference.

After squaring, To get the feature information a moving window integration algorithm is used. And the formula is:

$$y[n] = \frac{1}{N}\left(x[n] + x[n-1] + \ldots + x[n-(N-1)]\right) \tag{7}$$

Here N is related to the sampling rate. In our task the sample rate is 20 samples/sec, so here N is 10.

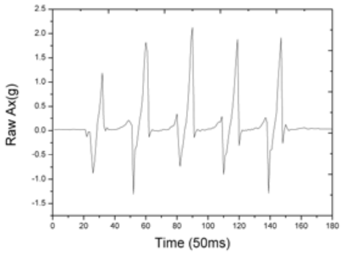
After the operation above, the x-axis of accelerometer can not be fused with the y-axis of gyroscope in direct. They must be normalized before data fusion. The normalized factor is their range.

The data fusion is calculated from

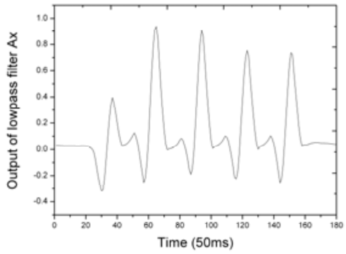
$$Y(n) = \sum_{n=1}^{M} \frac{A_n}{A_1 + A_2 + \ldots + A_M} X(n) \tag{8}$$

4. Results and Discussion

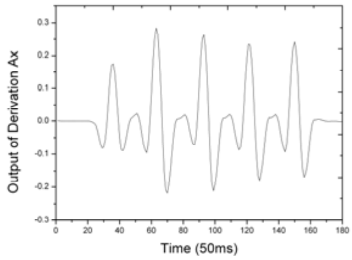
After the operations above, the algorithm based on the fused signals of the x-axis of accelerometer sensor output and y-axis of gyroscope sensor output are shown in Fig 6, Fig 7 and Fig 8.



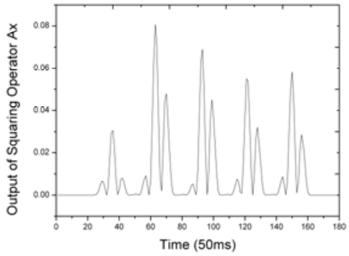
(a)



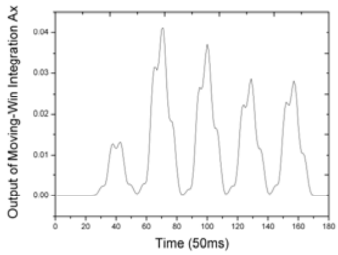
(b)



(c)



(d)



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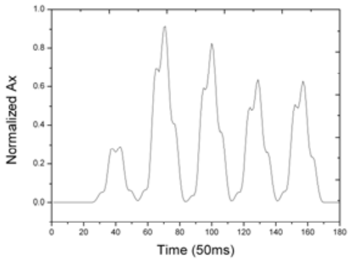
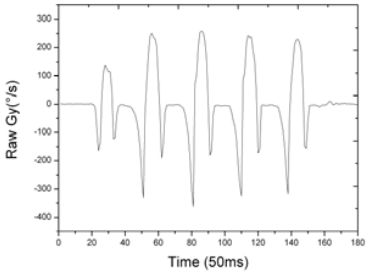
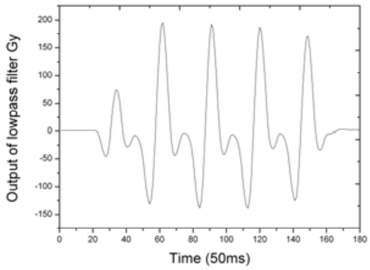


(f)

Fig.6. x-axial data of accelerometers on the right foot when walking; (a) Original X-axial Acceleration; (b) After Lowpass Filtered; (c) After Derivation; (d) After Squaring operator; (e) After Moving-Window Integration; (f) After Normalized;



(a)



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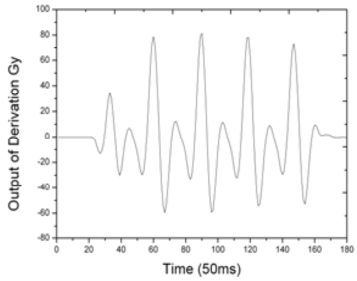

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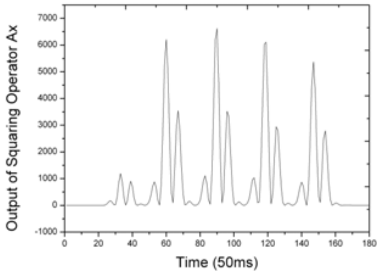

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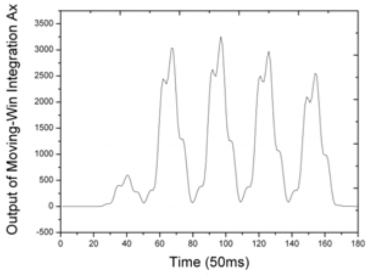

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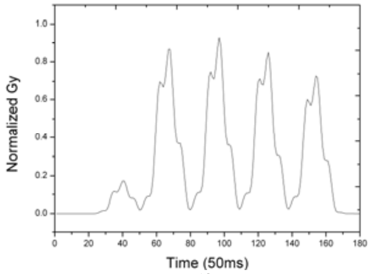

(f)

Fig.7. y-axis of Gyroscope output on the right foot in step procedure; (a) Original Y-axial of Gyroscope; (b) After Lowpass Filtered; (c) After Derivation; (d) After Squaring operator; (e) After Moving-Window Integration; (f) After Normalized;

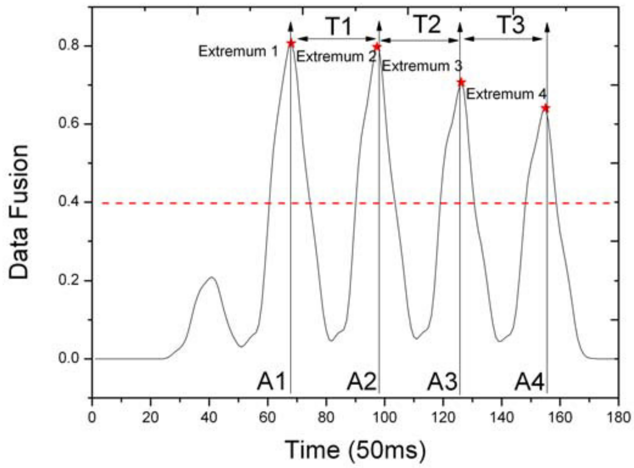

Fig.8.The results of the algorithm.

At the last, we used two thresholds to identify the extremums or not. The higher threshold identifies extremum value. The lower of the two thresholds is used when no extremum value has been detected in a certain time interval.

As shown in Fig.7, we can find out the extremum value array An; So the gait cycle array Tn is described by the formula:

$$Tn = (A_{n+1} - A_n) * T_s \tag{9}$$

Where Ts is sampling period; Refer to the Wearable Action Recognition Database (WARD)[11] from UC Berkeley, our sampling period Ts is 50ms.

In order to verifying the algorithm, Ten simulation gait cycle data of left foot of Parkinson patient is tested, and the results are showed in Table 1.

Table 1.Ten gait cycle data of left foot

	Walk slowly(left foot)				Walk fast(left foot)		
Gait Num	Extremum Value	An	Tn（s）	Gait Num	Extremum Value	An	Tn（s）
0	41			0	37		
1	69	69		1	46	46	
2	99	99	1.50	2	68	68	1.10
3	127	127	1.40	3	91	91	1.15
4	156	156	1.45	4	116	116	1.25
5	183	183	1.35	5	140	140	1.20
6	213	213	1.50	6	163	163	1.15
7	245	245	1.60	7	187	187	1.20
8	275	275	1.50	8	211	211	1.20
8	281			8	223		
9	306	306	1.55	9	234	234	1.15
10	336	336	1.50	10	258	258	1.20
10	343			10	269		
11	364	364	1.40	11	283	283	1.25

This paper presents a method of recognizing gait cycle characters using Wireless Inertial Sensor network. The wireless inertial sensor network is embedded in a pair of shoes with accelerometers and gyroscopes to measure inertial signal during walking. And the step cycle detected from the inertial signal of the foot gives useful information for gait analysis.

Based on shoes embedded with inertia sensor, we develop one method using peak detection of combined inertia sensor signal. The method designed for this purpose is easy to implement, can give the extremum array which can be used to calculate the step continuity, step regularity, step symmetry and so on from the inertial signal in real time.

5. Future Work

All of gait data above is collected among healthy adults. This system still needs to be validated among patients such as Parkinson. In the future, this system and the algorithm will be verified based on the real data from the patients.

Additionally, capacitive sensors and photoelectricity sensors will be embedded in shoes for other gait parameter in the nearly future.

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