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Novel Algorithm for the Hemiplegic Gait Evaluation using a Single 3-axis Accelerometer

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Abstract—**This paper suggests the novel algorithm for the estimating gait parameters of the hemiplegic patients using a 3-axis accelerometer. The signal processing for algorithm consists of a bandpass filter and a least square acceleration filter. To evaluate the performance of the algorithm, the correlation coefficients of the stride and the step time between the 3-axis accelerometer and the Vicon motion analysis system are compared. In consequence, correlation coefficient ranged from 0.90 to 0.99 for patients and ranged from 0.92 to 0.99 for normal subjects. The results showed that the novel algorithm is very useful for estimating not only hemiplegic gait but also normal gait.**

I. Introduction

HEMIPLEGIC gait evaluation is very important to assess the before and after of patients' rehabilitation therapy. For objective gait evaluation, various motion capture systems using infrared and ultrasound were used [1]. However, these systems are not often easily accessible in clinical settings, expensive and not potable.

In order to overcome these shortcomings, various and realistic methods for normal gait evaluation using the accelerometer are developed to monitor ambulatory and long-term daily activity [2]. Some researchers used two or multiple accelerometers to increase the accuracy of the gait evaluation algorithm [2]. However, the use of the multiple accelerometers interferes with movement. Also, it is unknown whether these methods are indeed incredible in hemiplegic gait.

Thus we developed a novel algorithm for evaluating the hemiplegic gait using one 3-axis accelerometer attached on the surface of the second sacrum. The developed algorithm is able to apply to normal gait as well as hemiplegic gait.

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TABLE I
UNITS FOR MAGNETIC PROPERTIES

		Sex	Age	Height (cm)	Weight (kg)	Hemiplegic Part	FAC [3]
Normal	N1	M	22	178	79	-	-
	N2	M	23	185	76	-	-
	N3	M	20	170	67	-	-
	N4	M	26	163	56	-	-
	(Average)		23	174	70	-	-
Patient	P1	M	71	178	63	Right	3
	P2	F	46	158	57	Left	4
	P3	M	48	171	70	Right	5
	P4	F	54	170	80	Right	2
	P5	M	67	162	62	Left	3
	P6	F	54	157	57	Left	5
	(Average)		57	166	64	-	-

II. Materials & Measurements

A. Subjects

A convenient sample of four healthy young adults and six hemiplegic patients after stroke volunteered and provided informed consent prior to the participation in this study. All patients were treated or are being treated in the Wonju City Medical Center in Republic of Korea. Table 1 presents detailed information of the subjects' characteristics.

B. Instrumentation & Data acquisition

Only one 3-axis accelerometer was placed on the surface of the second sacrum. To evaluate the algorithm, two reflective markers were attached on heel of the each leg and then the data were acquired using a motion capture system based on six optical cameras. The accelerometer and the reflective marker data were synchronously captured at 120 Hz sampling rate while the subjects walked on the 8-meter long walkway at their self-selected speed. All subjects walked 4 times repeatedly.

III. Algorithm for the Gait Step Detection

A. Finite Impulse Response Bandpass Filter

Raw data acquired from the accelerometer were filtered by the finite impulse response (FIR) bandpass filter because there is need to emphasize the main peak or valley point of the accelerometer data at the heel contact. Thus, the baseline components of the accelerometer data using 360th order FIR bandpass filter (bandwidth = main frequency ± 0.1Hz at AP & VT data; main frequency ± 0.05Hz at ML data) are removed such as (1).

$$ACC_R = ACC - ACC_{BP} \quad (1)$$

ACC_R : Accelerometer signal that removed the baseline
ACC : Raw accelerometer signal
ACC_{BP} : Bandpass filtered accelerometer signal

B. *Least Square Acceleration (LSA) Filter*

The FIR bandpass filtered data is processed to more emphasize the main peak or valley point of the accelerometer data using the LSA filter. The LSA filter is one of types of the FIR filter and was suggested to estimate the sharpness or the differentiation of the discrete signals [4]. The LSA filter is powerful for noise elimination and is able to compute real-time data. The coefficient of the filter is decided by the sharpness of the data.

In this study, we used the sixth order LSA filter experimentally.

C. *Detection of the Directional Gait Step*

A) Antero-Posterior Direction (Fig. 1): Detailed procedure for detecting gait step is as follows:

(1) Select the highest peak point of the ACC_{LSA} at the region between the peak points of the ACC_{BP}.

(2) Select the lowest valley point of the ACC_R when the valley point of the ACC_R is appeared twice time from the region before 4-sample of the peak point of the ACC_{LSA}.

(3) Determine the gait steps at the ACC from the selected valley points at the ACC_R.

B) Medio-Lateral Direction (Fig. 2): Detailed procedure for detecting gait step is as follows:

(1) Select the lowest valley point of the ACC_{LSA} at the region between the valley point and the next peak point of the ACC_{BP} for detecting right step. Select the highest peak point of the ACC_{LSA} at the region between the peak point and the next valley point of the ACC_{BP} for detecting left step.

(2) Select the point when the peak point of the ACC_R is detected from the region before 3-sample of the valley point of the ACC_{LSA} for detecting right step. Select the point when the valley point of the ACC_R is detected from the region before 3-sample of the peak point of the ACC_{LSA} for detecting left step.

(3) Determine the right and left steps at the ACC from the selected peak and valley points at the ACC_R.

C) Vertical Direction (Fig. 3): Detailed procedure for detecting gait step is as follows:

(1) Select the lowest valley point of the ACC_{LSA} at the region between the valley points of the ACC_{BP}.

(2) Select the highest peak point of the ACC_R when the peak point of the ACC_R is appeared twice time from the region before 4-sample of the valley point of the ACC_{LSA}.

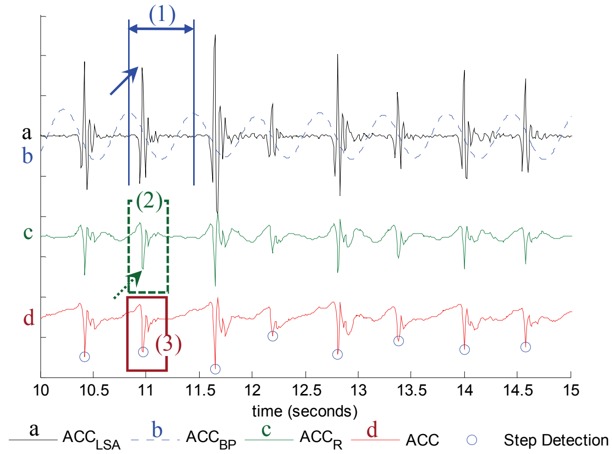

Fig. 1. Gait step detection procedure for antero-posterior acceleration data (Left hemiplegic gait).

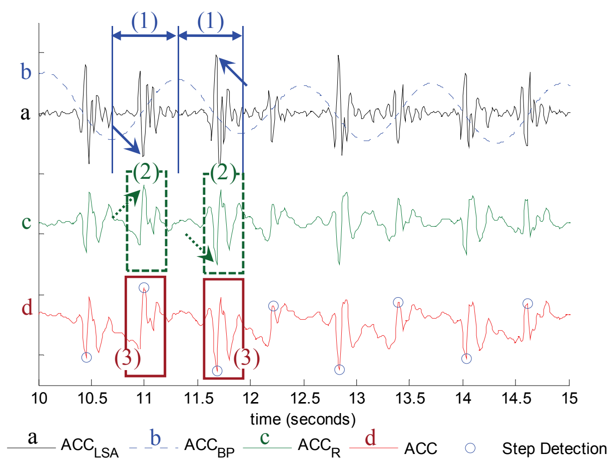

Fig. 2. Gait step detection procedure for medio-lateral acceleration data (Left hemiplegic gait).

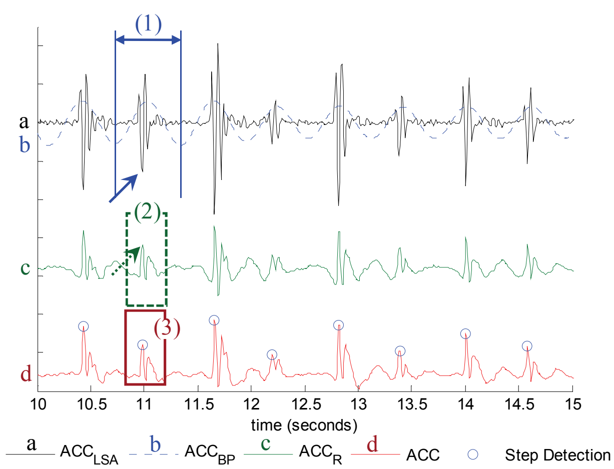

Fig. 3. Gait step detection procedure for vertical acceleration data (Left hemiplegic gait).

ACC_{LSA}.

(3) Determine the gait steps at the ACC from the selected peak points at the ACC_R.

D) Final procedure for gait step detection: Three directional gait steps detected by above method are not in same time position. Finally, procedure for detecting time position of the gait step is needed. If the gait step is detected at one or more direction data of the three directional data, the sample time might be counted from the sample time position of the detected gait step to the sixth sample of the detected gait step of the other directional data. And then, if the gait step is detected at two or more directional data during the six samples, the mean sample time of the detected gait step of the three directional data might be calculated to detect final gait step time.

IV. Results & Discussion

A. Results & Discussion

A novel algorithm for hemiplegic gait evaluation using a 3-axis accelerometer that is attached on the surface of the second sacrum is developed. For this, gait steps that classified each direction are detected. And then, final gait steps decided by each direction gait steps are detected. The stride time and step time is computed by final gait steps. To evaluate the algorithm performance, the correlation coefficients of the step and the stride time between the 3-axis accelerometer and the Vicon motion capture system are compared. Fig. 4 highlights compared results of the stride time and the step time that computed by the accelerometer and the heel marker for the patients and normal subjects. Correlation analysis revealed the correlation coefficient ranged from 0.90 to 0.99 for patients and ranged from 0.92 to 0.99 for normal subjects, indicating good to excellent validity.

Some previous researchers used a treadmill for analyzing the hemiplegic gait using the accelerometer [5]. But, it is unknown whether the gait steps of the subjects are detected exactly. In this study, however, the six optical camera motion capture system is used to evaluate the developed algorithm performance.

Also, we have used the least square acceleration filter to emphasize main peak or valley point of the accelerometer data. This filter was effective to detect the gait steps at the heel contacts using the accelerometer attached on the surface of the second sacrum for not only hemiplegic gait but also normal gait.

B. Limitations & Further Study

The limitations of this study are as follows. First, many trials were not performed because of the hemiplegic patient's fatigue. So, all subjects walked just 4 times repeatedly. Second, the number of the participants is small. Therefore, further study with a larger sample size in hemiplegic patients must be done a same way. Also, the suggested algorithm should be evaluated for the Parkinson's diseases, cerebral palsy and children.

V. Conclusion

This study presents the novel algorithm for evaluating the hemiplegic gait using only one 3-axis accelerometer. For this,

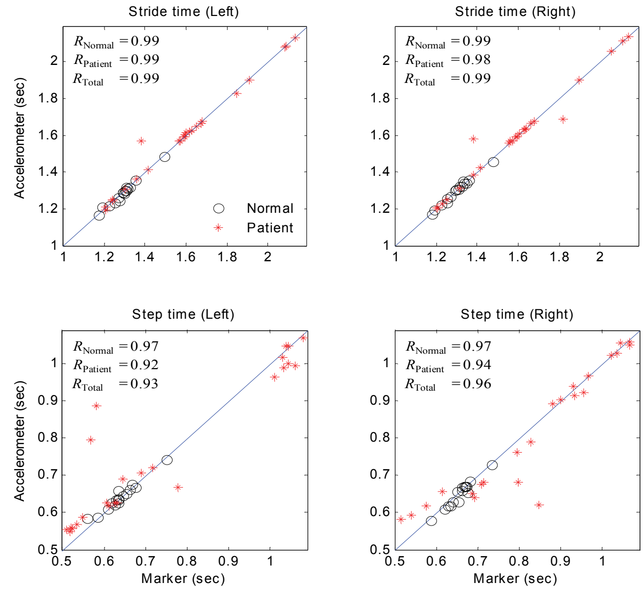

Fig. 4. Compared results of the stride time and the step time that computed by the accelerometer and the heel marker for the patients and normal subjects (*R*: correlation coefficient).

the FIR bandpass filter and least square acceleration filter were used to detect the gait steps. The results showed that the novel algorithm is very useful for hemiplegic gait evaluation. Moreover, the algorithm is able to apply to normal subjects as well as hemiplegic patients. Our results suggest that the algorithm using the accelerometer is more comfortable than the conventional tools such as the motion analysis system and provide clinical insights when designing a portable and inexpensive gait evaluation tool for hemiplegic patients.

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