Gait Event Detection using Tilt Sensor for Portable FES System

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Abstract

Functional electrical stimulation (FES) can be used to correct foot drop and toe drag during hemiplagic walking. We have focused on the portable measurement of gait phase of patients with hemiplagia. In this study, we performed gait analysis of normal and hemiplagic walking with and without Functional electrical stimulation. In addition, we have detected in gait phase using tilt sensor. We have constructed 3D motion analysis system for gait analysis of normal and hemiplagic walking. One healthy adult male subjects and one adult subjects with hemiplagia participated. Tilt sensor was used accurately to detect gait phase. The results have shown advantages of the gait event system using tilt sensor. It is expected that this study gives information about portable FES assistive walking system.

1 Introduction

Functional Electrical Stimulation (FES) can improve the gait of stroke patients by stimulating the peroneal nerve in the swing phase of the affected leg, causing ankle dorsiflexion to clear toes from the ground [1-4]. To apply FES system effectively, we need a gait phase detection system that can accurately estimate gait phase and send immediate input signals to the FES system. In general, 3-dimensional movement analysis system is widely used in analyzing gait phase, which is very accurate but very expensive. Besides, it is difficult to apply this system in a patient's daily life because it can only be used in the laboratory. Hence, there have been studies on sensors which can be applied effectively and simply to the FES system. Usually, when giving functional electric stimulus on legs to restore walking ability, patients themselves had to use hand-switches to set the stimulating time and foot-switches to detect gait phase [5]. This method had limitations because it had to be operated by hand, connected by wires, and not applicable to bear foot [6]. In previous studies, succeeded in detecting the angular speed of shank and thigh using two gyro sensors, and gait cycles by measuring the gradient to the gyrosensor's shaft [7]. Gait phase of stroke patients were determined using accelerometers [8]. Gait cycle detecting system was developed using FSR sensors and gyrosensor [9]. Even though the FSR-gyro sensor system might be more reliable for the gait phase detection in different applications, the simple tilt sensor system is not hindered by cables from the foot and could stimulate limbs at the same places where the detection is made. In this paper, we attached the tilt sensor along with the FES stimulating pad on the shank, and detected gait cycles of a normal person and a hemiplegic patient. In addition, we experimented whether 1-channel FES stimulus trigger signals are generated, using the voltage of gait cycles detected from the normal and hemiplegic walking.

2 Method

2.1 Subjects

A healthy male and a right hemiplegic patient were participated in this study. The patient was asked to walk as the convenient speed which was 30cadence without any assistance of FES walking system. After that, the healthy subject was asked to walk in a two different cases which are the walking with 30cadence and the walking with 30cadence assisted by FES walking system.

2.2 3D Motion Analysis System

An six-camera, three dimensional motion analysis system (VICON612, UK) was used to record kine-matic data at 120 Hz. The three dimensional motion analysis system (VICON612, UK), synchronized with a FES walking system and a tilt sensor, were used for the gait analysis of the two subjects. Temporal-spatial parameters and joint angles were used whether the tilt sensor signal was useful for a FES walking system. All data were processed and synchronized using Matlab before the analysis.

2.3 FES System & Foot Switch

The Walking-Man II was used to electrical stimulation in this study (Cyber Medic, KR). A foot switch is placed in the shoe under the heel. The frequency of
FES was set at 20Hz, the pulse width at 0.3us and the Stimulation duration at 1 second. Foot switch was used to trigger the FES during the swing phase of the gait phase.

![Foot Switch](image1)

Fig. 1  (a) Functional Electrical Stimulation ES System (b) Foot Switch

### 2.4 Tilt Sensor System

The SMD-type tilt sensor (SCA 100T, VTI, Finland) was integrated on the stimulation pad. Its measurement range was ±90° with sensitivity of 2V/g. Tilt sensor integrated stimulation pad (TSISP) was mounted on the motor point of the tibialis anterior (TA) in Fig.3 (b). When the foot lay in front of the knee joint, the tilt signal was positive value.

![Tilt Sensor](image2)

Fig. 2  (a) Tilt Sensor Integrated FES electrode (b) FES electrode location on the TA

### 2.5 Data Processing Unit

For tilt sensor data processing and transfer, a small data processing unit has been developed. Tilt sensor signal is sampled at 250Hz with 10bit resolution using this data processing unit. Tilt sensor signal can be digitized and transferred to the computer of VI-CON612 system using Bluetooth communication.

![Data Processing Unit](image3)

Fig. 3  (a) Diagram (b)Real pictures of the data processing unit

### 3 Result

#### 3.1 Normal Walking without FES

Healthy subject was asked to walk with a cadence of 30steps/min. Fig. 4(a) shows the ankle joint angles and the tilt sensor signal without the electrical stimulation. Red solid line means the initial contact and blue dotted line means the toe off which was determined by the foot switch, the same as the three dimensional motion analysis result. The positive peak and negative peak in the tilt signal was considered as important to determine the gait event for electrical stimulating. Fig. 4(b) showed that the tilt signal can be used for the FES walking system instead of the foot switch. Its time difference between the peak point and the gait event line on the picture was under the 6ms.

![Tilt Sensor Signal](image4)

Fig. 4  (a)Right Ankle Joint (b)Tilt sensor signal

( normal subject, 30 cadence, without FES)

#### 3.2 Normal Walking with FES

Fig. 4 shows the knee and ankle joint angles and tilt sensor signal during simulated patient walking. In this case, the electrical stimulation period was almost the same with the tilt sensor peak period (from positive peak to negative peak). The time differences were measured under the 6ms between the peak point and the gait event line.
3.3 Patients Walking without FES

During a hemiplegic patient's walking, the knee and ankle joint angles and tilt sensor signal were analyzed the same as above. In this case, the time difference between the tilt signal peak point and the gait event were measured in 2ms(initial contact) and 6ms(toe off).

![Fig. 3](a)Right Ankle Joint (b)Tilt sensor signal

HC, TO

(patient subject, 30 cadence, without FES)

3.4 Patients Walking with FES

Fig. 6 shows the ankle joint angles and tilt sensor signal during a hemiplegic patient's walking with electrical stimulation. In this case, the time difference between the tilt signal peak point and the gait event were measured in 2ms(initial contact) and 6ms(toe off). Ankle joint angle were more dorsiflexion(14°) then hemiplegic patient's walking without electrical stimulation.

![Fig. 4](a)Right Ankle Joint (b)Tilt sensor signal

HC, TO

(patient subject, 30 cadence, with FES)

4 Discussion and Conclusion

In this study, gait cycles of normal person and hemiplegic patients have been detected using the tilt sensor signal on shanks, through the TSISP.

Both in the healthy and patient gait, tilt sensor could detect the gait event for stimulation successfully. On the base of these results, we are performing to develop a portable FES walking system using a tilt sensor. In the future, we will develop a multi-channel FES walking system for paraplegic patients using complex and wireless sensor system.

Acknowledgments

This study was supported by a grant of the Korea Health 21 R&D Project, Ministry of Health & Welfare, Republic of Korea. (02-PJ3-PG6-2V03-0004).

3 Reference