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FES assisted swing-through gait using accelerometer and neural network

Matsunaga T [1], Misawa A [1], Sato M [1], Chida S [1], Hatakeyama K [1], Shimada Y [2], Shirahata T [2], Takeshima M [2], Iwami T [3], Iizuka K [4]

[1] Rehabilitation Division, Akita University Hospital, 1-1-1 Hondo, Akita, 010-8543 JAPAN
[2] Division of Orthopedic Surgery, Department of Neuro and Locomotor Science, Akita University School of Medicine
[3] Department of Mechanical Engineering, Akita University Faculty of Engineering and resource Science
[4] BIOTEC, Ltd

E-mail: matsu@med.akita-u.ac.jp

Abstract

In this study, FES assisted swing-through gait system using an accelerometer and a machine learning technique (neural network) was described. A spinal-cord injured patient (incomplete T12 lesion) volunteered for this study. One 2-axis accelerometer was used for the detection of swing-through gait events. For Neural Network training, acceleration data was processed with the input data, and the infrared rays data from infrared rays sensor and heel data from heel sensor were processed with the target data. FES assisted swing-through gait was successfully reconstructed by the neural network controllers. The average speed was 0.53 ± 0.06 m/s (Mean ± SD), average stride time was 2.20 ± 0.26 s, and average stride length was 1.22 ± 0.09 m. The present system has a potential to access the reconstruction of FES assisted swing-through gait with free-knees in paraplegic patients.

1 Introduction

The swing-through gait is a fast and effective gait pattern for paraplegic patient who are able to perform it. Heller and colleagues first reported the clinical study of functional electrical stimulation (FES) assisted swing-through gait with free-knees, and concluded that it is shown to be a potentially useful mode of FES gait [1].

For the successful reconstruction of FES assisted swing-though gait, it is important to detect gait cycle and stimulate lower limb muscles automatically. Using artificial intelligence, FES controllers have been developed that allow the automatic phasing of stimulation, to replace the function of hand or heel switches [2]. For the reconstruction of swing-through gait, there is a possibility of detecting a gait cycle using an acceleration sensor and a machine learning technique (neural network). The purpose of this study was to design the FES assisted swing-through gait system using an accelerometer and neural network.

2 Methods

2. 1 Subjects

An incomplete paraplegic patient (male, 57 years, 178 cm, 61 kg) volunteered for this study. The cause of paralysis was spinal cord injury due to falling. The injury level was low-thoracic level (T12). ASIA impairment scale was C. Prior to the FES assisted swing-through gait, the subject had undergone the swing-through gait training using axillary crutch and knee-ankle- foot-orthoses (KAFOs).

2. 2 Experimental settings

One 2-axis accelerometer (ADXL 202: Analog Devices, Inc., Tokyo, JAPAN) was used for the detection of swing-through gait cycles. The acceleration sensor was mounted on the ADXL 202 evaluation board and positioned on right side of the axillary crutch. We measured changes in acceleration during swing-through gait in the sagittal and gravitational directions of the crutch. Signals from a heel sensor (Click BPG, Tokyo Sensor, Inc., Tokyo, JAPAN) and infrared rays sensor (GP2D12: SHARP, Inc., Osaka, JAPAN) were used for the target signals. The infrared rays sensor was placed on right side of the axillary crutch to detect the body swing through the crutches in the gait cycle. The heel sensor was placed under the heel on the right side to provide reference points for the heel off in the gait cycle. The signals were recorded using a ND-2000 recorder (KEYENCE, Inc., Osaka, JAPAN).

For the neural network training, the subject walked on the laboratory floor by swing-through gait using axillary crutches with KAFOs. The data from sensors were input to a personal computer, and was processed using a learning form. We calculated bias and weight of the neural network using MATLAB (Cybernet System, Inc., Tokyo, JAPAN) and the Neural Network Toolbox (The MathWorks, Inc., Natick, MA, USA). We wrote a neural network program including weight and bias, using the computer programming language C, and forwarded the program to a microcomputer (H8/3048F: HITACHI, Inc., Tokyo, JAPAN). The microcomputer produced output signals using the neural network program, in real time.

2. 3 Evaluations of FES assisted swing-through gait

Subject was performed FES assisted swing-through gait on the laboratory floor. During the body stance phase, Quadriceps muscles were automatically stimulated via surface electrodes (Figure 1).
Kinematic data of the gait was recorded by using computer video-based integrated three-dimensional system for human motion analysis (Peak Motus® Motion Measurement Systems, Peak Performance Technologies, Inc., USA). Prior to data acquisition, reflective markers were placed on fifteen anatomical locations on the subject as follows: bilateral positions of the shoulder, elbow, hip, knee, ankle, and foot. An additional marker was placed on the neck (C7 level) and the bilateral axillary crutch tips. The accuracy of the microcomputer output data (stimulation signal) was compared with the motion analysis data.

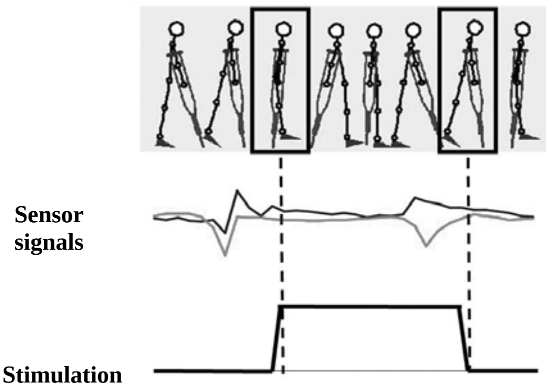

Figure 1. Sensor and stimulation signals during FES assisted swing-through gait

3 Results

FES assisted swing-through gait was successfully reconstructed by the neural network controllers (Fig 1). The average speed was 0.53 ± 0.06 m/s (Mean ± SD), average stride time was 2.20 ± 0.26 s, and average stride length was 1.22 ± 0.09 m.

4 Discussion and Conclusions

In the present study, an acceleration sensor and a neural network were used to detect swing-though gait cycles. We were able to reconstruct the FES assisted swing-through gait with free-knees in an incomplete paraplegic patient. The neural network detector could correspondingly predict the beginning of gait cycles.

In some cases, FES has been used to maintain the knees locked in extension throughout the gait cycle in the reconstruction of FES assisted swing-though gait. This method emulates the role of long leg braces and is still expensive in energy cost. FES assisted swing-through gait with knee free is adequate for reducing this energy cost. The present system (an acceleration sensor and the neural network) has a potential to access the reconstruction of FES assisted swing-through gait with free-knees in paraplegic patients.

References

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