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Gait phase analysis based on a Hidden Markov Model

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ABSTRACT

For effective gait rehabilitation treatments, the status of a patient's gait needs to be analyzed precisely. Since the gait motions are cyclic with several gait phases, the gait motions can be analyzed by gait phases. In this paper, a Hidden Markov Model (HMM) is applied to analyze the gait phases in the gait motions. Smart Shoes are utilized to obtain the ground reaction forces (GRFs) as observed data in the HMM. The posterior probabilities from the HMM are used to infer the gait phases, and the abnormal transition between gait phases are checked by the transition matrix. The proposed gait phase analysis methods have been applied to actual gait data, and the results show that the proposed methods have the potential of tools for diagnosing the status of a patient and evaluating a rehabilitation treatment.

1. Introduction

There is a steady rise in demand of gait rehabilitation treatments as the number of patients or elderly people who suffer from gait disorders is increasing [16,10,15]. For effective gait rehabilitation treatments, the status of a patient's gait needs to be analyzed precisely. Usually, the status of a patient's gait is analyzed by physical therapists with visual observations or verbal descriptions. Since these qualitative diagnostic methods depend on physical therapists' experience and knowledge, more objective methods to analyze patients' gaits are required.

Since the gait motions are cyclic with several gait phases, the gait motions can be analyzed by the gait phases [11]. The gait phases are observed by various gait data such as foot pressure distributions and joint angles. Due to the easiness and the practicality of measuring foot pressure distributions, shoe-type sensors have been devised by previous researchers. Also based on the measured foot pressure distributions, several methods for the detection of gait phases have been suggested. Morris and Paradiso developed a shoe-integrated sensor system for wireless gait analysis and real-time feedback [7]. Bamberg et al. developed a shoe-integrated wireless sensor system by applying four force sensitive resistors (FSRs) and a bend sensor [2]. Pappas et al. made a gait phase detection system with three FSRs and a gyroscope [9]. These researches, however, detected the gait phases as discrete events, which is not correct in actual gait motions.

In the previous works, a fuzzy logic was applied for the continuous detection of gait phases with the ground reaction forces (GRFs) measured by Smart Shoes [5,4]. Smart Shoes were developed to measure GRF embedded air-bladder type force sensors. By utilizing the GRF patterns in the fuzzy logic, the gait phases are detected continuously and smoothly. The fuzzy logic method uses fuzzy membership functions and fuzzy rule bases shown in Fig. 1. Due to the use of FMV and fuzzy rule bases, the fuzzy logic method can be considered as a pattern-based gait phase detection method. To determine "Large" and "Small" of the fuzzy rule bases in Fig. 1, the fuzzy member functions of (1) and (2) were applied.

$$f^{Large}(x) = \frac{1}{2}[tanh(s(x - x_0)) + 1] \quad (1)$$

$$f^{small}(x) = 1 - f^{small}(x) \quad (2)$$

where s, x and x_0 represent the sensitivity coefficient, the measured GRF and the threshold value. The threshold values are determined manually to distinguish the large value and the small value, and they are usually selected as small values such as about 5% of the body weight for the detection of the little contact to the ground and the fast response. But the small threshold values make it easy to have a large value in f^{Large}. For example, suppose that the threshold value for the heel is set to 30 N, and the actual GRF at the heel is measured 300 N for the heel strike. Then the f^{Large} is large enough even though actual GRF of the heel is not enough for the heel strike. Thus, if the sequence or the timing of each GRF are quite correct and the GRF values are larger than the threshold values for "Large" in the fuzzy rule bases, then the fuzzy rule bases in Fig. 1 can be satisfied regardless the actual GRF values. In other words, the fuzzy logic method may detect the gait phases wrong as normal gait phases if the GRF data have the similar patterns with a normal gait. The experimental results by the fuzzy logic and the proposed method are compared in Section 5.2. For the details about the fuzzy logic method, see [5,4].

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