A Knowledge Based System for the Selection of Muscles for Gait Phase Detection using EMGs

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ABSTRACT

Purpose: This paper presents the development of a knowledge based system for the detection of gait phases based on EMGs from muscles of the lower limb. Methods: An empirical analysis of the EMG characteristics for the most representative muscle of every muscle group concerning their suitability for the gait phase detection is presented. The same approach is applied to every lower limb muscle where an EMG could be received. The entities and the decision-making mechanism of the knowledge based system is presented in a formal way. Results: A knowledge based system is built upon the knowledge acquired from this analysis. Finally, an example is presented where the developed knowledge based system is used to support the conceptual design of a drop foot correction system. Conclusions: The knowledge based system can be used in the conceptual design of any rehabilitation system for lower limb disabilities using EMG signals from the lower limbs.

KEYWORDS
EMGs, Expert Systems, Knowledge Based Systems, Lower Extremity, Rehabilitation

INTRODUCTION

An accurate, reliable and clinically reasonable method to detect critical gait events is required towards improving the human locomotion by restoring the functionality of weak or paralyzed lower extremity muscles. Thus, gait event detection received considerable attention based on a combination of hardware and sophisticated software algorithms. Various signal sources are used for gait event detection including foot switches (Ng, 1997), accelerometers (Crago et al., 1996), angle velocity’s (Lyons et al., 2002) and nerve’s sensors (Hansen, 2001) among others.

When foot switches are used, an appropriate positioning is required to obtain a reliable detection for each subject, especially those suffered from pathological gait (Smith et al., 2002). A frequent maintenance is required since these sensors suffer from the initial contact impact. Information content is limited, unless sophisticated algorithms like fuzzy inference systems (Skelly et al., 2001) are employed, or there is an increase in the number of the attached foot switches (Smith et al., 2002). Accelerometers and combinations of accelerometers with angle velocity’s sensors are used for the detection of the Initial Contact (IC) event in cases of the lower limb pathology, called Drop-Foot Syndrome (Lyons et al., 2002). Various devices are developed such as accelerometers and gyroscopes
based on recent advances in miniaturization, which were used for offline (Jasiewicz et al., 2006) and online gait event detection (Hanlon & Anderson, 2006). Gonzalez et al (2010) introduced a heuristic rule-based algorithm for the real-time detection and timing of the Initial Contact (IC) event between two gait cycles, processing vertical and antero-posterior accelerations registered at the lower trunk.

The aforementioned sensor choices presuppose the placing of sensors onto or into (implantable sensors) the patient limbs with a number of issues still pending, such as sensor maintenance, donning, cosmetic, etc. Moreover, gait event detection is conducted in the laboratory, where the force that a patient applies during walking is measured using a force plate. Gait event detection is performed by processing kinematic data obtained with video-cameras and markers, placed on the patient during human locomotion. Although force plates and kinematic data processing methods are often considered to be the “gold standard” for determining gait events, these are laboratory methods and cannot be used for rehabilitation purposes.

Another source for gait event detection and rehabilitation control is an electromyographic (EMG) signal. The use of EMG for switching either the initiation or ending an action for the control of upper limb Functional Electrical Stimulation (FES) systems was reported in (Nathan, n. d.; Hart, 1998). Further elaborated control schemes, such as the use of a time-delayed adaptive neural network (TDANN) to predict movements of the shoulder and elbow for an upper limb FES system (Au & Kirsch, 2000) or a fuzzy inference system (FIS) extracting information from the EMG signal to operate an externally powered prosthesis (Park & Lee, 1998), were proposed.

Gait event detection using EMG signals from voluntarily controlled muscles was proposed by two research groups. Kordylewski and Graupe (2001) acquired surface EMG signals from upper trunk muscles to predict intended lower extremity movements for reciprocal walking or postural corrections for static standing using neural networks. Lauer et al (2005) tested the feasibility of gait event detection by reading the intramuscular EMG from a lower limb muscle, called quadriceps, using a Fuzzy and a Neuro-Fuzzy network, in children with cerebral palsy. The results were very promising towards using data from lower limb muscles EMGs for the development of gait event detection techniques and rehabilitation control.

In addition, the EMG signal is attractive for gait phase detection and rehabilitation control for the following reasons. Proximal lower extremity muscle activity occurs in a repeatable way with respect to the gait cycle (Hof et al., 2002). The technology achieved fully implantable tiny recording electrodes (Smith et al., 1998), instead of using other implantable larger and more complex sensor devices that require extensive maintenance and donning.

One of the critical problems, in using lower limb muscles EMG for gait phase detection is the large number of the lower limb muscles that can be used, around thirty (30), in relation to the seven (7) gait phases and one (1) event (IC). In addition, although it is expected that during a normal gait cycle every lower limb muscle presents one repeatable EMG pattern for all humans, there are muscles that present two EMG patterns (Perry, 1992).

Apart from the normal gait pattern there is a great variety of pathological gait patterns that do not follow the EMG normal patterns. This is usually noticed in patients that suffer for a long time from pathology of a lower limb and as a result even healthy muscles adopt a pathological pattern in order to counterbalance the pathological limb behavior. It is possible that not all the healthy lower limb muscles have changed their normal EMG patterns, but some of them will.

This paper presents the development of a new method for the detection of gait phases based on EMGs from muscles of the lower limb. An approach is introduced for the analysis of the EMG characteristics concerning their suitability for the gait phase detection towards deriving a mapping between the phases to be detected and the most suitable muscles, from where the EMGs could be received. “Suitable” muscles are addressed to the issues of finding solutions where pathological and
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