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Human movement onset detection from isometric force and torque measurements: A supervised pattern recognition approach

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ABSTRACT

Objective: Recent research has successfully introduced the application of robotics and mechatronics to functional assessment and motor therapy. Measurements of movement initiation in isometric conditions are widely used in clinical rehabilitation and their importance in functional assessment has been demonstrated for specific parts of the human body. The determination of the voluntary movement initiation time, also referred to as *onset time*, represents a challenging issue since the time window characterizing the movement onset is of particular relevance for the understanding of recovery mechanisms after a neurological damage. Establishing it manually as well as a troublesome task may also introduce oversight errors and loss of information.

Methods: The most commonly used methods for automatic onset time detection compare the raw signal, or some extracted measures such as its derivatives (i.e., velocity and acceleration) with a chosen threshold. However, they suffer from high variability and systematic errors because of the weakness of the signal, the abnormality of response profiles as well as the variability of movement initiation times among patients. In this paper, we introduce a technique to optimise onset detection according to each input signal. It is based on a classification system that enables us to establish which deterministic method provides the most accurate onset time on the basis of information directly derived from the raw signal.

Results: The approach was tested on annotated force and torque datasets. Each dataset is constituted by 768 signals acquired from eight anatomical districts in 96 patients who carried out six tasks related to common daily activities. The results show that the proposed technique improves not only on the performance achieved by each of the deterministic methods, but also on that attained by a group of clinical experts.

Conclusions: The paper describes a classification system detecting the voluntary movement initiation time and adaptable to different signals. By using a set of features directly derived from raw data, we obtained promising results. Furthermore, although the technique has been developed within the scope of isometric force and torque signal analysis, it can be applied to other detection problems where several simple detectors are available.

1. Introduction

During the last decade the application of technologies such as robotics to functional assessment and motor therapy has been successfully introduced [1,2]. Encouraging clinical results have been achieved [3].

Among the parameters measured by a rehabilitation machine that can be used as significant markers for clinical purposes, the time window characterizing the movement onset is of particular relevance to understand recovery mechanisms after a neurological damage [4]. In this respect, the determination of the voluntary movement initiation time, also referred to here as *onset time* (OT), is a relevant issue. Indeed, OT should reflect how the central nervous system processes sensorimotor information [5], and it has been used also in other fields of neuro-physiological investigation, such as the assessment of neurological conditions in patients suffering from Parkinson's disease [6,7].

Various instruments can be used to acquire information on movement onset, such as an electromyograph or an isometric

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platform. While the former would require the use of a needle to perform intramuscular electromyography (EMG), the latter is thoroughly non-invasive. One isometric platform is the Alladin Diagnostic Device (ADD), a mechatronic system measuring the force and torque of motor efforts during movement preparation and initiation for tasks related to activities of daily living (ADLs) [8,9]. The basic hypothesis underlying its development is these measures can provide useful information for functional recovery of patients affected by a stroke [4,8].

However, humans are limited in their ability to determine movement onset from recorded signals for several reasons, e.g. their non-systematic search patterns, the poor reproducibility of OT estimates [10], or their dependence on movement profile [11]. Moreover, in applications using force and torque signals, movement initiation in isometric conditions is often hard to detect because of noise and the weakness of the signal. Hence, OT detection via "direct" analysis of signals is not only a troublesome task, but it may also cause oversight errors or loss of useful information.

In order to overcome the limitations of manual ticking, in the last decade research was directed towards the development of systems which may establish OT automatically [5,12–15]. The most commonly used detectors are typically based on single threshold approaches, which determine OT through the comparison of the raw signal, or some extracted measures such as its derivatives (i.e., velocity and acceleration) with a chosen threshold. However such methods, which we also refer to as *deterministic methods* in this paper, suffer from high variability as much as systematic errors [5,11,16] due to the quality of the signal, the abnormality of response profiles and the variability of movement initiation times among patients.

Some recent papers proposed different OT deterministic estimators for ADD signals [4,8], but their performance assessed on real data is no better than those achieved by manual ticking of clinical experts.

This paper proposes a technique for automatic OT detection overcoming the aforementioned limitations, by choosing the detection method best suited for any given signal from a pool of onset estimators. The choice is performed by a supervised pattern recognition system using information directly derived from the signal. This technique was tested on annotated force and torque signals acquired through ADD, and it shows that it improves not only on the performance achieved by any deterministic methods, but also on the performance obtained by a group of clinical experts.

The rest of the paper is organized as follows. Section 2 presents the ADD and the background on OT detection. Section 3 presents the proposed technique, whereas Section 4 introduces features extraction and selection. Section 5 contains the description of the datasets, of the experimental protocol and of the results. Section 6 concludes the paper.

2. Background

2.1. ADD: force and torque measurement

Isometric measurements are already widely used in clinical rehabilitation and their importance in functional assessment has been widely demonstrated for specific parts of the human body [17]. Indeed, a quantitative approach for a functional assessment of subjects affected by injuries and/or pathologies relies on recording their movements. In the first period after a stroke the range of motion of some movements may be limited. In these cases, measurements of movement initiation in isometric conditions can be used for assessment purposes. The scientific rationale of this approach is given by recent findings in neurorehabilitation, which suggest that voluntary movement initiation has the same functional properties of an actually performed task [18–20]. Furthermore, the analysis of movement initiation in isometric conditions could provide useful information for basic neuroscience research on motor control and planning.

Fig. 1. Alladin Diagnostic Device (ADD).

ADD (Fig. 1) can measure the force and torque of motor efforts during movement preparation and initiation in isometric conditions for specific tasks. Six different ADL tasks were used to collect quantitative measurements related to changes in functional performance [21]. ADD integrates force and torque sensors with six degrees of freedom over eight body districts on the patient. In particular, force and torque measurements are recorded from the thumb, the index and the middle finger of the impaired hand, on the seat, on the back and on the impaired foot and big toe, during the preparation and initiation of six specific ADL tasks (grasping a glass, turning a key, taking a spoon, lifting a bag, reaching a bottle, moving a bottle). Force and torque data are simultaneously acquired from the eight sensors via a dedicated software. The acquisition period ranges between four and six seconds, depending upon the task. The sampling frequency is 100 Hz for each sensor. The interested reader cam find further details on the experimental protocol in previous works [4,9] and project deliverables [22,23].

It is worth observing that signal acquisition from different body districts introduces a huge variability. Fig. 2 shows the different nature of signals to be analyzed and the consequent difficulty in OT determination using a fixed criterion. Panels (A) and (B) show the signals of two different patients recorded from the left thumb, whereas panels (C) and (D) depict two signals from the same patient acquired from two different body districts (right thumb, right arm). It can be observed that signal structures change considerably depending on the body position, the performed task, the patient and other parameters. This variability mostly affects the correctness of the method used for OT detection; thus a deterministic method can produce acceptable results for signals with a given structure, but at the same time it can perform poorly with other types of signals.

2.2. Methods for OT detection

In biomedical research and clinical application, detectors commonly used to detect OTs are based on single threshold approaches [5,11,16].

For example, in case of electromyography (EMG) signals some recent contributions have indicated possible solutions to overcome