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Classification of physical activities based on body-segments coordination

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Numerous innovations based on connected objects and physical activity (PA) monitoring have been proposed. However, recognition of PAs requires robust algorithm and methodology. The current study presents an innovative approach for PA recognition. It is based on the heuristic definition of postures and the use of body-segments coordination obtained through external sensors. The first part of this study presents the methodology required to define the set of accelerations which is the most appropriate to represent the particular body-segments coordination involved in the chosen PAs (here walking, running, and cycling). For that purpose, subjects of different ages and heterogeneous physical conditions walked, ran, cycled, and performed daily activities at different paces. From the 3D motion capture, vertical and horizontal accelerations of 8 anatomical landmarks representative of the body were computed. Then, the 680 combinations from up to 3 accelerations were compared to identify the most appropriate set of acceleration to discriminate the PAs in terms of body segment coordinations. The discrimination was based on the maximal Hausdorff Distance obtained between the different set of accelerations. The vertical accelerations of both knees demonstrated the best PAs discrimination. The second step was the proof of concept, implementing the proposed algorithm to classify PAs of new group of subjects. The originality of the proposed algorithm is the possibility to use the subject's specific measures as reference data. With the proposed algorithm, 94% of the trials were correctly classified.

In conclusion, our study proposed a flexible and extendable methodology. At the current stage, the algorithm has been shown to be valid for heterogeneous subjects, which suggests that it could be deployed in clinical or health-related applications regardless of the subjects' physical abilities or characteristics.

1. Introduction

To characterise daily-life human movement and physical activity (PA) is fundamental to better understand, prevent, and treat human health issues [22,33,42]. Over the past ten years, many systems based on accelerometers or inertial sensors [11,12,17,2,24] have been proposed to enable ambulatory characterisation of movement [5]. Motion tracking sensors such as accelerometers and inertial sensors have the ability to measure kinematics over a long period of time whilst being relatively non-intrusive [1]. These developments have provided new opportunities particularly for the field of rehabilitation and many projects utilising these sensors have been undertaken for rehabilitation purposes [16,17,22,41,48]. The applications proposed aim mainly at monitoring subject's PA for a general physical activity assessment [17,49,22] or for a comparison with PA recommended by clinical staff [22,28].

Due to the low cost price of accelerometers, PA recognition algorithms are mostly based on signal processing from acceleration signals of one or more accelerometers placed on different body segments e.g the pelvis [21,37,7,13], the chest [34,37], the wrist [51,13], the thigh [37], the lower-leg [20,34], and the ear [26]. Many different signal processing are also proposed [2], including classification techniques [38,13] decisional trees [21,34,7], k-nearest neighbour classifier [37], Hidden Markov Model [19], and neural networks [34,25]. The inputs of the classifiers could be temporal data, frequency-domain features and also time-frequency features [2,37]. However, these proposed methodologies still suffer from some drawbacks. Methods based on classifiers and have to be trained with data coming from subjects belonging to homogenous physical ability populations to whom the application is devoted [30]. Due to the large number of musculoskeletal diseases and possible disabilities, only a few rehabilitation applications are investigated e.g. ACL rupture, stroke gait. In addition healthy subjects have often been defined as the reference [34].

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Now, elderly, pathological or post-traumatic populations have specific physical abilities that differ greatly not only from those of healthy subjects but also from each other [30]. Consequently, the same whole process including data acquisition of subjects and classifier training has to be repeated for each targeted population [5]. Such data collection is laborious and sometime due to physical limitations impossible to achieve by some patient [5]. In addition, evolution of physical abilities is to be expected during the rehabilitation process [36]. Personalisation and time adjustment should then be taken into account when proposing an algorithm to classify physical activities.

The second main drawback of this traditional approach of PA recognition technique is that it hypothesizes that PA can be differentiated by separately processing motion tracking sensor signal. The recognition algorithm is thus based on the assumption that each PA to recognise induces different acceleration signals and this, whatever the position of the sensors on the body, whatever the pace of the PA [30]. Until now, feature extraction consists mainly of proposing signal processing features and testing their efficiency for PA recognition [3,37] by a retrospective point of view. The meaning and the relevance of these features for representing physical activity and human movements are not discussed nor justified.

In context of PA recognition, signals or state information are generated by humans with inter-subject variability due to intrinsic properties, modification and adaptation of the neuro-musculoskeletal system. As classical signal processing parameters use determinism hypothesis, large populations need to be studied whereas subject specificity can lead to misinterpretation.

Now, from a biomechanical point of view, each PA is characterised by a specific body-segments coordination, translated by a specific body-segments kinematics signature. For instance, cycling is characterised by a cyclical motion of the feet around the drive axis, which results in a typical coordination of the feet.

At the same time, over the past three decades, numerous motion capture studies have analysed human movement [50]. Biomechanical studies also investigated PAs currently performed and recommended in the rehabilitation context such as walking [32,36], running [31,32,46], or cycling [18,44]. These analyses have well enlightened that each PA is characterised by a specific body-segment coordination that is translated by a typical pattern of kinematic data [18,50]. However this knowledge is at this time not integrated in PA recognition algorithms.

The aim of the present study is to demonstrate and to provide the proof of concept of a PA recognition method integrating knowledge of human biomechanics. For this, a PA recognition algorithm architecture both easy to individualise and adjustable is proposed. Then, a methodology allowing defining which set of kinematics data representing body-segment coordination is most relevant to discriminate different activity types is presented. Then a demonstration of the relevance of the kinematics data representing body-segment coordination is included. Finally, a proof of concept based on a design experimentation involving subjects of different age, morphology, and various physical activity level is presented. The approach has the specificity to take the subjects' own data as reference data in order to be efficient whatever the subjects physical abilities or particularities would be.

2. Material and method

2.1. Architecture of the algorithm

The algorithm proposed to recognise the sitting/standing/lying postures as well as the PAs walking/running/cycling. The PAs walking, running, and cycling were chosen because they represent three popular aerobic physical activities recommended in rehabilitation programs [15]. The positions of sitting, lying, and standing were also performed since these postures are important for detecting sedentary behaviour [4].

The general architecture of the algorithm is shown in Fig. 1. The algorithm considers only body-segment accelerations and orientations as inputs. If the body segment accelerations are below the threshold T_1, the subject is considered as being immobile and

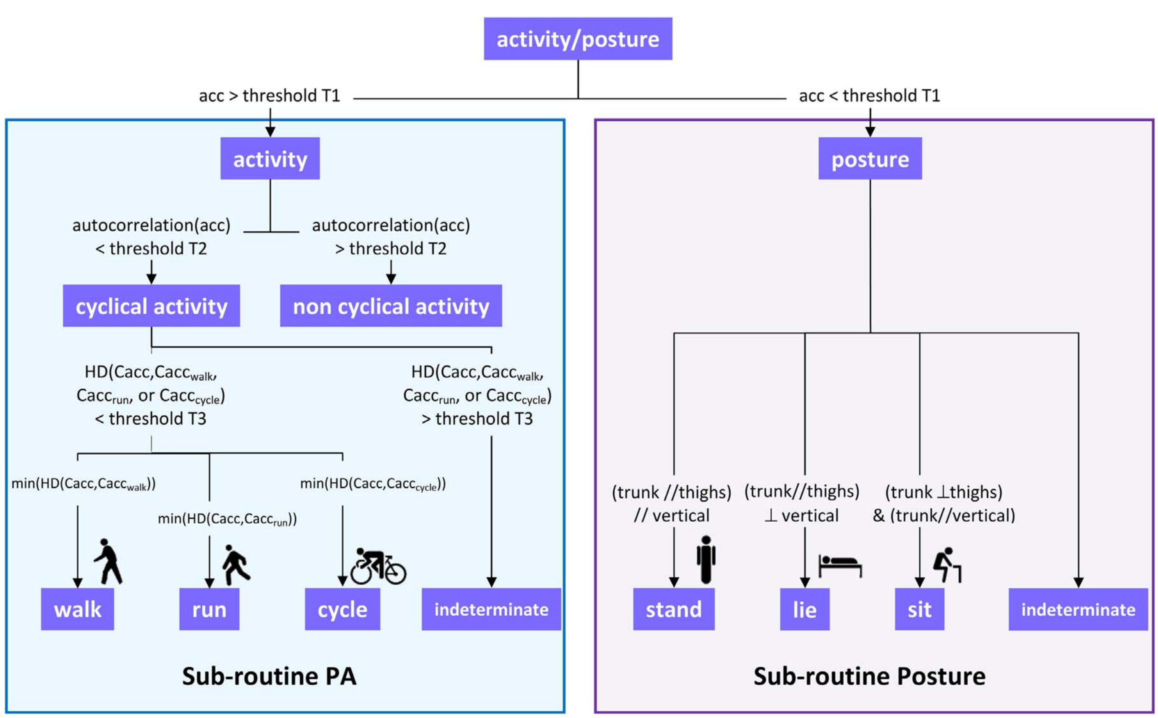

Fig. 1. Algorithm for the PA classification; acc represents accelerations of the activity/posture to classify; $Cacc_{walk}$, $Cacc_{run}$, $Cacc_{cycle}$ represent *n*-space reference curves corresponding to *n* accelerations for subject specific reference activities "walking", "running" and "cycling".