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Linguistic description of the human gait quality

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ABSTRACT

The human gait is a complex phenomenon that is repeated in time following an approximated pattern. Using a three-axial accelerometer fixed in the waist, we can obtain a temporal series of measures that contains a numerical description of this phenomenon.

Nevertheless, even when we represent graphically these data, it is difficult to interpret them due to the complexity of the phenomenon and the huge amount of available data. This paper describes our research on designing a computational system able to generate linguistic descriptions of this type of quasi-periodic complex phenomena.

We used our previous work on both, Granular Linguistic Models of Phenomena and Fuzzy Finite State Machines, to create a basic linguistic model of the human gait. We have used this model to generate a human friendly linguistic description of this phenomenon focused on the assessment of the gait quality. We include a practical application where we analyze the gait quality of healthy individuals and people with lesions in their limbs.

1. Introduction

Human beings describe phenomena in our environment using natural language (NL). In order to perform this task, we interpret the available data using our experience in both, namely, the field of knowledge that allow us to recognize the phenomena and our experience on using NL.

Our research line deals with the design and development of a new family of computational systems capable of generating linguistic descriptions of complex phenomena, i.e., these computational systems obtain data from a phenomenon and provide linguistic descriptions that are relevant for specific users in specific contexts. This type of systems will be used in supervision and control applications and especially in the development of user interfaces based on the use of NL.

Human gait is a quasi-periodic phenomenon which is defined as the interval between two successive events (usually heel contact) of the same foot (Begg et al., 2007). This process is characterized by a stance phase (that approximately takes 60% of the total gait cycle), where at least one foot is in contact with the ground, and a swing phase (approximately 40% of the total gait cycle), during which one limb swings through the next heel contact. Gait phases can be quite different between individuals but when normalized to a percentage of the gait cycle they maintain close similarity, indicating the absence of disorders (Perry, 1992). Fig. 1 shows two different synchronized pictures. The top picture plots a sketch of a person representing the different phases of the gait with the right limb boldfaced. The picture at the bottom represents the time period from one event (usually initial contact) of one foot to the subsequent occurrence of initial contact of the same foot.

Due to the fact that human gait is a complex integrated task which requires precise coordination of the neural and musculoskeletal system to ensure correct skeletal dynamics (Winter, 1990), its analysis can help in the diagnosis and treatment of walking and movement disorders, identification of balance factors, and assessment of clinical gait interventions and rehabilitation programs (Hamacher et al., 2011; Lai et al., 2009; Moustakidis et al., 2010; Sant'Anna et al., 2011; Wren et al., 2011).

In human gait analysis, there are a huge number of variables obtained by means of different measurement techniques. Most gait parameters can be categorized as anthropometric data which include height, weight, or limb length; spatiotemporal data comprising variables such as walking speed, step length, or phases time span; kinematic data of measurements of joint angles, displacement, or acceleration along axes; kinetic data variables including foot force and torques; or electromyographic data which measures the muscle activation levels.

Two of the most common approaches to manage and analyze human gait kinematic data are the computer vision approach (Tafazzoli and Safabakhsh, 2010) and the sensor-based one. The main advantage of the computer vision approach is the avoidance of placing sensors on the user's body. However, an expensive and

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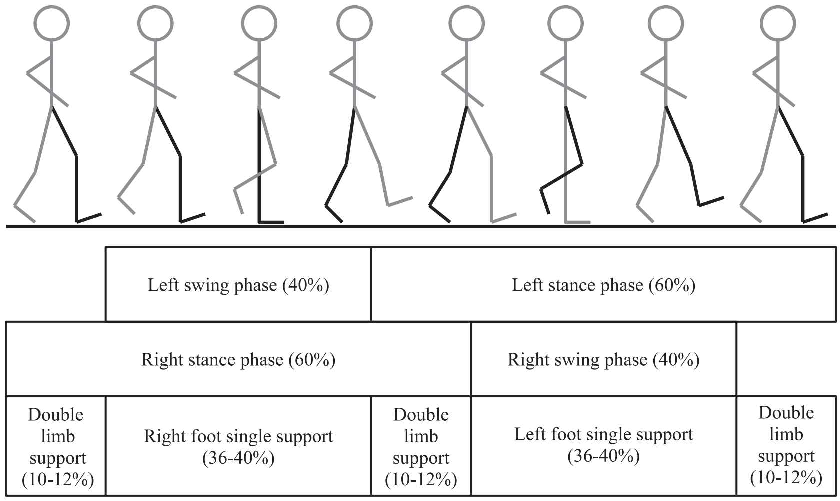

Fig. 1. One gait cycle illustrating the four main phases.

complex system for capturing images is needed. Moreover, these methods usually work in lab but fail in real world scenarios due to clutter, variable light intensity and contrast. On the other hand, the sensor-based approach consists of using small sensors (usually accelerometers) placed in the body of the person. This solution provides a smart solution to the problem of capturing the signal, where data can be obtained anywhere by means of a smartphone. Moreover, they can be used in the dark and provide three-dimensional data. This line of research has attracted an important number of researchers that focus the problem of human gait modeling from different perspectives (see, e.g., Alaqtash et al., 2011; Najafi et al., 2003).

Our approach is based on the Computational Theory of Perceptions (CTP). This field was introduced in the Zadeh's (1999) seminal paper "From computing with numbers to computing with words—from manipulation of measurements to manipulation of perceptions" and further developed in subsequent papers. CTP provides a framework to develop computational systems with the capacity of computing with the meaning of NL expressions, i.e., with the capacity of computing with imprecise descriptions of the world in a similar way that humans do it. In CTP, a granule is a clump of elements which are drawn together by indistinguishability, similarity, proximity or functionality (Zadeh, 1979). The boundary of a granule is fuzzy. Fuzziness of granules allow us to model the way in which human concepts are formed, organized and manipulated in an environment of imprecision, uncertainty, and partial truth (Zadeh, 1997). A granule underlies the concept of a linguistic variable (Zadeh, 2008). A linguistic variable is a variable whose values are words or sentences in NL (Zadeh, 1975a,b,c).

In this paper, we do an extensive use of our previous research, contributing to the human gait quality analysis field by providing a new technique for modeling this type of phenomenon. We have developed a computational application that uses a single three-axial accelerometer to generate linguistic descriptions for assessing the human quality. Here, we develop upon our previous research on the Granular Linguistic Model of a Phenomenon (GLMP) improving its expressiveness by introducing a new type of components based on the concept of Fuzzy Finite State Machine (FFSM). First, we identify the relevant phases of the gait based on the accelerations produced during the process. Once the phases are recognized, we use two relevant features of the human gait (homogeneity and symmetry) to evaluate the gait quality corresponding to a specific person. Finally, we develop a method for producing a linguistic report about the quality of the gait in terms of the homogeneity and the symmetry. This type of reports could be used to analyze the evolution of the human gait, e.g., after a recovery treatment and also for preventing falls in elderly people.

The remainder of this paper is organized as follows. Section 2 presents the main concepts of our approach to linguistic description of complex phenomena evolving in time. Section 3 describes how to use these concepts for the linguistic description of the human gait quality. Section 4 describes the experimentation carried out, by describing the experimental setup and discussing the results. Finally, Section 5 draws some conclusions and introduces some future research works.

2. Linguistic description of phenomena evolving in time

Our approach to computational model of phenomena is based on subjective perceptions of a domain expert that we call the designer. The more experienced designer, with better understanding and use of NL in the application domain, the richer the model with more possibilities of achieving and responding to final users' needs and expectations. The designer uses the resources of the computer, e.g., sensors, to acquire data about a phenomenon and uses her/his own experience to interpret these data and to create a model of the phenomenon. Then the designer uses the resources of the computer to produce the linguistic utterances.

In this section, we introduce the components of the GLMP, our approach based on CTP for developing computational systems able to generate linguistic descriptions of phenomena (Alvarez-Alvarez et al., 2011a; Eciolaza and Trivino, 2011; Mendez-Nunez and Trivino, 2010; Trivino et al., 2010b).

2.1. Computational perception (CP)

A *CP* is the computational model of a unit of information acquired by the designer about the phenomenon to be modeled. In general, *CP*s correspond to particular details of the phenomenon at certain degrees of granularity. A *CP* is a couple (A, W) where:

$A=(a_1,a_2,\ldots,a_n)$ is a vector of n linguistic expressions (words or sentences in NL) that represents the whole linguistic domain of the *CP*. Each a_i describes the value of the *CP* in each situation with specific granularity degree. These sentences can be either simple, e.g., a_i="*The dorso-ventral acceleration is high*" or more complex, e.g.,