DYNAMIC SIMULATION OF HUMAN MOTION

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ABSTRACT

In order to study the mechanisms behind the human motion and its disorders, and to comprehend how do neuromuscular impairments affect the human movements, it is crucial to know the human musculoskeletal system. This knowledge is also essential to effectively model and analyse the musculoskeletal system, and to classify the human movement. With this work we conducted preliminary studies over a musculoskeletal model in motion, and performed a comparative analysis in gait between two models: one with a non-pathological gait and another with a disordered gait.

INTRODUCTION

The study and simulation of the human motion arouses great interest within the scientific community. Considerable investigation has been conducted in this field of knowledge, as evidenced by the several surveys that have been published over the recent years: Ke et al. (2013), Aggarwal and Ryoo (2011), Poppe (2010), Gavrila (1999).

Objectively, motion analysis aims to evaluate the motion whilst motion simulation uses the motion information to construct a dynamic virtual scenario. The number of potentially relevant applications that somehow make use of these knowledge is vast and their usage becomes fundamental in various domains, such as: (1) in sports, by helping athletes to understand, compare and improve their performances (Tseh et al. (2008)), as well as to reduce the number of their potential injuries. Besides, athletes can observe and learn new techniques (Syamsuddin and Kwon (2011)). For example, by simulating real world baseball data in order to support real batting practice in a virtual world; (2) in virtual reality, where the human motion can be captured and used to animate virtual characters, like in Nguyen et al. (2005), where it was presented a real-time system for capturing humans in 3D and placing them into a mixed reality environment; (3) in the design industry, by helping to reduce the number of physical prototypes, and consequently reducing expenses and the associated risk, and also to speed up the design process (Garcia et al. (2002)). In particular, the human motion can be used to design ergonomically safe environments, products and devices in practically all areas (prostheses, sports equipment, workspaces, etc.). An elucidative example presented by Mavrikios et al. (2006), the authors conducted an ergonomic study of the human posture while stepping into the car, and the output data of the models (either motion trajectories or joint angles of critical body segments) was further incorporated into human modelling software tools to drive digital human models, providing data on potential injury risk and postural analysis; (4) in health, where computer models and simulations of the musculoskeletal system are widely used to study the mechanisms behind human gait and its disorders. In fact, a better understanding of the human motion and its underlying dynamics is essential in developing more effective methods to comprehend how neuromuscular impairments affect motion (Audu et al. 2010), and to provide a scientific basis for treatment (e.g.: tendon transfers, physical therapy).

Many relevant engineering software applications have been developed with the purpose of analysing and/or simulating the human motion. We conducted a comprehensive and up-to-date survey of the most cited tools in order to choose one that best matched to our experimental work. From the studied tools (e.g.: Damsgaard et al. (2001), KWON (2012), OpenSim (2012), SIMI (2012), SIMM (2012), Visual3D (2012)) we concluded that: most of them have a closed architecture, disabling the possibility to be expanded through new modules or components; only a small set of them is freely available; regarding to modeling issues, all of them have capabilities for creating and editing models, and most of them have a model repository. Concerning to simulation capabilities, only half of them can simulate the human motion, whilst all can perform motion analysis (some at two dimensions and others at two and three dimensions).

Taking into account these considerations, we decided to use OpenSim (Delp et al. 2007) for our experimental work. Mainly because it is an open-source package with an open architecture, which enables users to extend it by writing their own plug-ins for analysis or control, or to represent neuromusculoskeletal elements. Also because it has a Neuromuscular Models Library (NML), enabling users to build, exchange, and analyze computer models of the musculoskeletal system and to perform dynamic simulations of movement. And finally, because it has a powerful graphical user interface which gives access to a suite of high-level tools for viewing models, editing muscles, plotting results, among other functions. In this work we modeled our own simplified version of a musculoskeletal model and studied the model's movements by computing all the joints' angles and moments using experimental motion data. We also performed a comparative analysis in gait between two models: one with a non-pathological gait and another with a disordered gait.

HUMAN MOTION SIMULATION EXPERIMENTS

The main goal of this study was to evaluate the human motion: in a first stage by using a simplified version of a musculoskeletal model, on which we applied simple motion data; and then, using a more complex model, by applying real motion data in order to analyze the differences in gait between two individuals. Thus, our first approach was to model a simplified version of a musculoskeletal model (the Upper Extremity model from the OpenSim's NML (see Figure 1)). These models comprise a set of components corresponding to parts of the physical and computational system, and represents the physics of a mechanical system containing bodies and joints that are acted upon by forces in order to produce motion.

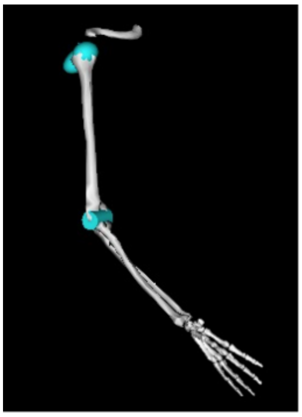

Figure 1: The Simplified Version of the Upper Extremity Model of the OpenSim's Neuromuscular Models Library

Then, we manually composed a basic experimental marker trajectory for a motion trial, in a "Track Row Column" ASCII file format, and then we reproduced it. This kind of motion data specifies the positions of a set of markers placed on a subject at different times during a motion capture trial. In order to reproduce the motion we applied the Inverse Kinematics simulation tool. The purpose of this tool is to find the joint angles of the model that best reproduce the experimental kinematics of a given subject. For that, it goes through each time step (frame) of the motion and computes generalized coordinate values which position the model in a pose that "best matches" the experimental marker and coordinate values for that time step. Mathematically, the "best match" is expressed as a weighted least squares problem, whose solution aims to minimize both marker and coordinate errors. A marker error is the distance between an experimental marker and the corresponding marker on the model, while a coordinate error is the difference between an "experimental coordinate value" and the generalized coordinate value computed by the Inverse Kinematics tool. Thereafter we computed the joints angles and moments during movement. On top of Figure 2 we can observe the elbow flexion (in blue) and the shoulder elevation (in red), and at the bottom, we can analyze the shoulder's joint moment (in red) and the elbow's joint moment (in blue), during the motion trial.

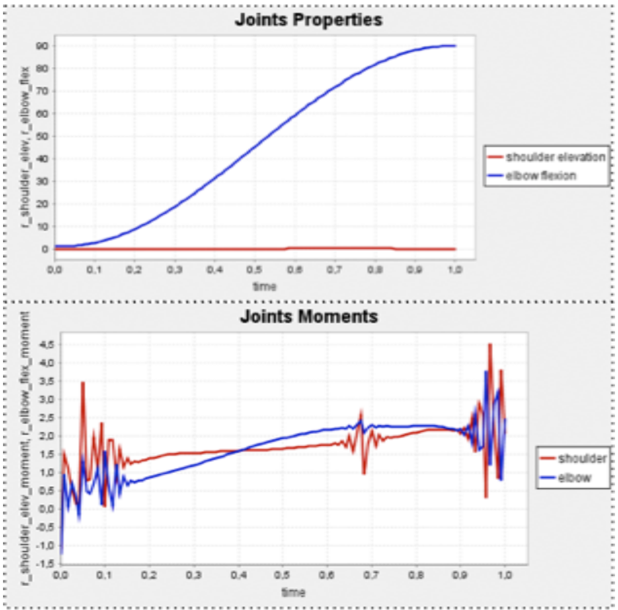

Figure 2: Graphical Representation of the Elbow Flexion and Shoulder Elevation (on top); Graphical Representation of the Elbow and Shoulder Joints Moments (on bottom)

Once concluded these initial steps, we intended to analyze the differences in gait between two individuals: one with a non-pathological gait and other with a crouch gait, which is one of the most common walking abnormalities among individuals with cerebral palsy. To accomplish this task we used two Lower Limb models from the OpenSim's Neuromuscular Models Library, and for each model we loaded the corresponding motion trajectory.

According to Whittle (2007), a pathological gait like crouch gait is characterized by excessive flexion of the knee during stance phase, which is often accompanied by exaggerated flexion and internal rotation of the hip. Therefore, in order to quantitatively compare both gaits, we computed the knee flexion angles over the two gait cycles, and as we can see in Figure 3, the knee angle curve of the pathological gait (in blue) follows the pattern previously described.

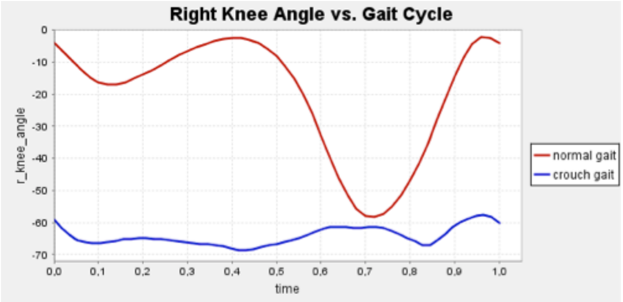

Figure 3: Graphical Representation of the Right Knee Angles of a Non-pathological Gait and of a Crouched Gait

CONCLUSIONS AND FUTURE WORK

Studies on human motion were and are quite interdisciplinary between biomechanics, computer graphics, and computer vision. Certainly, further areas are of relevance, like medicine (e.g., rehabilitation technology), robotics (e.g., studies on passive dynamic walking), or sports sciences (e.g. modeling of an athlete motion) are also important areas of application, revealing that this is a very active and attractive area, with many issues still open.

Regarding to this project, several improvements are intended to be carried as future work. First of all, we need to access a large dataset of human gaits (non-pathological and disordered). Then, although OpenSim is able to estimate parameters associated to motion, it does not reduce the data to relevant statistics or determine patterns related to motion. To address these limitations we need to identify the best features to extract and evaluate their weights to properly tune the similarity distance metric, using for instance, evolutionary algorithms (e.g. genetic algorithms). With this task it is expected to develop a pattern classifier that recognize the distinct motion patterns.

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