Human Motion Analysis and Simulation Tools

Resumo

Análise de movimento é actualmente um tópico de pesquisa bastante activo nas áreas da Visão por Computador, Computação Gráfica e Biomecânica, devido à sua aplicabilidade num vasto espectro de aplicações em diversas áreas. Com este trabalho pretendemos apresentar um detalhado, abrangente e atualizado estudo sobre aplicações de análise e/ou de simulação de movimento, que têm sido desenvolvidas tanto pela comunidade científica como por entidades comerciais. O principal contributo deste estudo, além da listagem abrangente de ferramentas de análise de movimento, é a apresentação de um esquema eficaz para classificar e comparar ferramentas de simulação e de análise de movimento.

Abstract

Motion analysis is currently an active research topic in Computational Vision, Computer Graphics, Machine Learning *and Biomechanics mainly due to its applicability into a wide spectrum of relevant applications in many areas. This work intends to present a detailed, broad and up to date survey on motion and/or simulation analysis software packages that have been developed both by the scientific community and commercial entities, to be used in the field of biomechanics. The main contribution of this study, beyond the comprehensive listing of motion analysis tools, is the presentation of an effective framework to classify and compare motion simulation and analysis tools.*

Keywords

Motion analysis, motion simulation.

1. INTRODUCTION

Motion analysis is a multidisciplinary research theme dedicated to the detection, tracking and understanding the physical behavior of moving elements. Although this is not a new topic of research, it has continuously receiving considerable attention within the communities of Computational Vision, Computer Graphics, Machine Learning and Biomechanics [Gavrila'99, Yilmaz'06, Poppe'07, Moeslund'06, Dariush'03]. In fact, looking back at our History, one can see that motion analysis has been a subject of investigation for a long time. The curiosity and the drive for understanding the world that surround us are natural qualities of the humankind. The fascination for the comprehension and the explanation of phenomena led to the observation of all aspects of daily life and to the construction of knowledge. The study of the human, animal or mechanical movements is part of that search, and many researchers gave their contribute within this fields. Among the renowned researchers, Leonardo da Vinci (1452–1519) was one of them. He made anatomical studies of the bone, of the muscle and of the nerve. Some of his drawings described the mechanics of the body during standing, walking up and downhill, rising from a sitting position, jumping, and human gait. Giovanni Alfonso Borelli (1608-1679) also gave his contribution by clarifying the muscular movement and body dynamics. By writing "*De Motu Animalium*", where he applied into the biological world the geometric analysis used by Galileo (1564-1642) in the field of mechanics, made him "the father of biomechanics". During the 19th century the Weber brothers analyzed the human gait and provided a theory of locomotion resulting in the publication of the book "On the Mechanics of the Gait Tools". Later, the French scientist Etienne-Jules Marey (1830–1904), during his motion studies, applied a set of mechanisms to a runner in order to record his movements. He also designed a special camera that recorded several phases of the motion into one photo. Inspired by this recording of motion technique, Eadweard Muybridge (1830–1904) proposed a new solution for recording fast motion, where he used a series of 12 cameras. He also developed a machine to display the recorded series of images. This technique was used for recording fast motion of a galloping horse and also for human movement studies with different categories of locomotion. Muybridge, with his experiments called "Animal Locomotion" became known as the pioneer in motion capturing.

More recently, during the 20th century, many researchers had contributed to an increasing knowledge of human kinematics and kinetics [Baker'07]: John V. Basmajian (1921-2008) expanded electromyography techniques and understanding of muscle function; David A Winter (b. 1930) refined experimental techniques for the analysis of gait; David Sutherland (1923–2006) applied classic studies on the development of gait in children, and influence of cerebral palsy on gait; and Mary Pat Murray (1925-1984) applied classic studies on adult gait, learning many aspects of pathological walking.

Over the latest years, due to the technological evolutions in personal computers, in video analysis, and in laboratory data acquisition hardware, major contributions have been addressed to develop solutions that became faster, more robust, more accurate, massively distributed, and eventually with a lower cost of production. Many relevant engineering software applications have been developed with the purpose of analyzing and/or simulating human motion. The usage of these tools becomes fundamental in various areas of movement science.

This paper presents a detailed, broad, and up to date survey on human motion and/or simulation analysis software packages that have been developed both by the scientific community and commercial entities to be used in the field of biomechanics. The main contribution of this study, beyond the comprehensive listing of motion analysis tools, is the presentation of an effective framework to classify and compare motion simulation and analysis tools. For the mentioned purpose a set of relevant features is identified and described. As the main outcome, the surveyed tools are classified in respect to the proposed framework and a comparative overview of all the analyzed tools is summarized in a table.

The paper is organized into four sections: after this introduction, next section presents fundamental concepts and related work in respect to human motion analysis and simulation. The herein conducted survey and proposed classification framework are presented in Section 3. In a last section (Section 4) main conclusions are drawn and future work developments are pointed out.

2. HUMAN MOTION ANALYSIS AND SIMULATION

The analysis of human actions comprises the acquisition of the human motion, using an invasive or a noninvasive system, and then its assessment. In the invasive systems, the subject under study wears markers that usually are placed near each joint to identify the motion by the positions or angles between the markers. This procedure presents some drawbacks, including the mere fact of having to place the markers on the subject, which is in fact time consuming, as well as the use of artifacts that can significantly change the pattern of locomotion during walking, as demonstrated in [Fisher'03]. The noninvasive systems conduct a video-based motion capture, with no resort to markers. This is a challenging problem with many issues that need to be handled: poor imaging with motion blurred; occlusions; illumination changes; multiple moving objects; multimodal mapping, since an image observation can represent more than one pose, among others.

The perception of human motion it is an essential task for a wide range of applications and depending on the usage that it is given to this motion data, applications can be grouped under three different classes: surveillance, control and analysis [Moeslund'06].

Surveillance applications cover some of the most classical types of problems related to automatically monitor human activities in security-sensitive areas such as airports or borders. They can be used to identify abnormal movements, perceive the actions of individuals, classify its nature, and consequently detect corresponding events and alarm situations, like a fall [Cucchiara'05]. This kind of applications can require a considerable effort from the human operators, since it is common to have several cameras that should be analyzed simultaneously.

Control applications are the ones capable of capturing physical movements and turning them into commands that will be used to control something. The film and game industries are the most popular costumers of this type of applications, using the recognition of human activity for gesture-based game interfaces and character animation. In games [Okada'07], a player's gestures and activities are used as commands for game control instead of pressing buttons on a keyboard or moving a mouse. Therefore, the player's movements must be detected, parameterized, and recognized with a sufficient level of accuracy, and it is important that this process must be simple enough for an audience to appreciate the connection between movement or gesture and the system's output. In character animation, human motion analysis is important to animators who wish to generate physically-based animations of humanoids [Lo'08]. Another field of usage of this type of control applications is in robotics, where the human motion data is used to animate and control robots, either with an humanoid appearance [Pollard'02] or other, like a wheelchair, for instance [Ju'09]. In most of the cases presented, there is the need to deal with the fact of having to operate in real time.

Analysis applications can be used in different scenarios, where the motion data is reduced to relevant features for comparison and classification purposes. The ability to obtain quantitative assessments of motion has significantly fostered the improvement of several areas of knowledge. In sports, for example, the biomechanical analysis of the movements of athletes can help them to understand and improve their performances or even facilitate the recovery process after injuries. In the work reported in [Dempsey'12] the authors presented a study about athletes catching a ball in different overhead positions, which may affect landing postures and knee joint moments. Another scenario is in the human engineering field, where the motion data is used to design new office furniture, new products and new workstations, or to study phenomena related to human postures during their occupation [Grujicic'10, Okunribido'03]. Another branch of uses is in the car industry with applications for automatic control of airbags, sleeping detection, pedestrian detection, lane following, etc. (see [Viola'05]).

In medicine, the study of human motion can be also extremely valuable. The human gait is one of the most important movements for the development of the human being life. Each human movement involves a skeleton and several muscles bending, stretching, compressing and rotating in complex ways. A good understanding of the human motion, taking into account the biomechanical foundations and the physiology of the elements involved, is extremely important. It can help to reveal the distinct patterns that classify a particular movement [Boyd'05]. For example, stroke victims exhibit movements that are distinctive from healthy people, and it would be useful to be able to identify those features in their motion [Schroeder'95]. With effective classifiers it's possible to have quicker diagnoses and more effective rehabilitation techniques that specifically address the needs of the individual patient. Many studies have been carried out on patient's gait analysis, including cerebral palsy [Harvey'11], multiple sclerosis [Sosnoff'12], Parkinson's [Sarbaz'12], amputees and neurological problems.

Simulations using motion capture data can make predictions of movements based on changes to muscles, positions, and forces. In fact, simulations offer many advantages opposed to experiments. They can be used to evaluate and design products and processes, helping to reduce the number of physical prototypes, as well as expenses and the associated risk, and to speed up the design process [Garcia'02].

3. PROPOSED CLASSIFICATION FRAMEWORK

Since the aim of this work was to present a detailed and up to date study on motion and/or simulation analysis software packages that have been developed both by the scientific community and commercial entities, we conducted a comprehensive research to select the most cited tools within the literature. Scientific papers, from several journals and conference proceedings, that mentioned the use of this kind of applications during their research process, supported this selection. We have also consulted the official web pages of research laboratories whose focus is related to motion analysis and simulation.

Thereafter, we defined a set of features that we considered to be the most relevant to describe the chosen software tools. These would include a set of generic features, a set of modeling capabilities features, a set of data acquisition features, and a set of analysis and simulation features.

3.1 General Features:

The first set of features attempts to characterize the tool in a generic manner. It comprises:

i. The tool latest version and its release date, giving a sense of maturity of the application;

ii. The information specifying whether the tool began as an academic project or not, and in case of affirmative, indicate the seminal paper (whenever possible);

iii. The software availability, i.e., whether it is a free or a commercial product;

iv. Openness of the software architectures, in particular what are, if available, the mechanisms to extend the tool with custom functionalities, as for instance: open source, software development kits (SDK) and application programming interfaces (API), plugin developments or scripting.

v. The ability to export the resulting data from motion analysis, allowing further analysis using other tools;

vi. The ability to store the patients profile as well as their trials and sessions for easy comparison of "before and after" scenarios.

3.2 Modeling Features

The second set of features describe the modeling capabilities of each tool, indicating:

i. The possibility to create and/or edit models;

ii. If the tool has its own collection of models that can be used.

It is very important that a software solution enables users to develop and edit their own models, and that they have available a set of predefined whole-body and/or body-part models.

3.3 Data Acquisition Features

The third set refers to the data acquisition features, mentioning:

i. If the tool has a native, external or absent motion capture system;

ii. If the tool imports analogue data, identifying all the sources of the data (C3D/EMG/force plates).

The synchronization of all signals allows technical personnel to evaluate simultaneously how the patient moves the articulations, uses his or her muscles and exchanges forces with the ground during the stride cycle.

3.4 Analysis and Simulation Features

The analysis and Simulation set of features refers to:

i. The dimensionality of the motion analysis (2D, 3D or both);

ii. The timing that the analysis occurs (real time, offline or both);

iii. A flag indicating if the tool performs a kinematic analyses;

iv. A flag indicating if the tool performs inverse dynamic analysis; and

v. A flag indicating if the tool performs inverse kinematic analysis.

vi. The last feature indicates whether it is possible or not to simulate human movement.

One obstacle we faced during this work was the difficulty in finding all the needed information. In some cases we complemented the information we had with additional data supplied by the tools' authors or by the marketing departments of the companies that commercialize the tools.

Table 1 (see page after Section 5) presents the thirteen applications that took part of this study with all the previously described features already filled, resulting on an effective framework to classify and compare motion simulation and analysis tools. After examining the table we can draw some conclusions. We noticed that more than half of the tools were created or reviewed within the last two years, denoting to be a very active and attractive research area with a continuous interest by the scientific community and/or companies. Just a small set of the tools is freely available. Still, three of the commercial ones provide a trial version. Seven applications have their origin in projects initiated within the academic community, and currently four of them resulted in business. Most of the tools have their architecture closed, disabling the possibility to expand through new modules or components. Nevertheless, all of them export the computed data during the motion analysis, varying only in formats (text, excel, and others). Due to the diversity of usage of the reviewed tools, not all of them need to store information relative to patients. However, seven of them include this ability. With regard to modeling issues, all of the tools have capabilities for creating and editing models. Ten of them have a model repository that can be used. Concerning the data acquisition features, eleven applications use data derived from motion capture systems. Of these, seven have a native motion capture system and four an external one. Still, the applications that have no motion capture system also import analogue motion data. Only two tools do not import any analogue data, while the remaining tools support data from force platforms and/or from electromyography. Regarding the latest features, all the applications perform their analysis at three dimensions and seven of them also analyze at two dimensions. Six applications operate only offline while the remaining tools work both online and offline. All the tools compute kinematics analysis, and the majority also computes inverse dynamics. At last, just half of the tools can simulate the human motion.

4. CONCLUSIONS AND FUTURE WORK

Human Motion Analysis and Simulation (HMAS) is, since long time ago, an important and multidisciplinary research topic. Applications vary from diverse areas as medical, biomechanics, sports performance and human machine interaction.

Recent technological developments allow to provide researchers with automated and semi automated tools in order to model, analyze or simulate human motion. Several open problems, such as marker-less tracking, interactive and real time operation, full 3D acquisition, uncontrolled environments (lighting, occlusions, etc.) still remain.

This paper surveys the main concepts regarding to HMAS and the state of the art in respect to automated tools in human motion analysis and simulation (HMAS) is presented. The paper introduces our perspective on how HMAS tools can be classified and compared. A logical, structured and feature oriented classification framework is described and presented.

Key features are proposed to be grouped into five main categories: a) generic features - in order to accommodate qualities such as maturity, expansibility and availability; b) modeling features - in respect to main modeling capabilities; c) data acquisition - describing how and what data can be acquired for analysis purposes; d) analysis - describing the kind of analysis provided and; 3) simulation - indicating when simulation of human motion models is achievable.

A comprehensive and up-to-date survey of the most cited tools is presented and compared against the proposed framework.

As future work, and beyond keeping it up-to-date, we intend to extend the herein presented framework in respect to some particular technologies and approaches and refine it accordingly towards a full taxonomy of HMAS Tools.

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	Generic Features							Modeling		Data Acquisition		Analysis					Simulation
Tool	***Current Version***	***Academic Project [seminal paper]***	***Availability***	***Architecture***	***Exports Data***	***Patients profile***	***Create / Edit models***	***Library of models***	***Motion Capture (native – external -absent)***	***Analog Data***	***Dimensionality***	***Real-time - offline***	***kinematics***	***inv. dynamics***	***inv. kinematics***	
AnyBody Modeling System [AnyBody]	5.1.0 (2011.08)	Yes [Damsgaard'01]	Commercial (trial version available)	Closed	Yes	No	Yes	Yes	Absent	Motion data EMG Force plate	3D	Offline	Yes	Yes	Yes	Yes
BTS SMART-Clinic [BTS]	N/A (2010.09)	No	Commercial	Closed	Yes	Yes	-	-	External	Motion data EMG Force plate	3D	Both	Yes	Yes	No	No
DMAS6 Motion Capture Suite [DMAS]	N/A (2005)	No	Commercial	Open	Yes	Yes	Yes	Yes	Native	EMG Force plate	2D / 3D	Both	Yes	Yes	No	No
eHuman [eHuman]	6.0 (N/A)	Yes (York Univ. Canada)	Commercial (trial version available)	Closed	Yes	No	Yes	Yes	Native	Force plate	2D / 3D	Both	Yes	Yes	No	Yes
KAPro [KAPro]	7.1 (N/A)	Yes (San Francisco Univ. USA)	Free (educational institutions)	Closed	Yes	No	Yes	No	Native	-	2D / 3D	Offline	Yes	Yes	No	No
KWON3D XP [KWON]	4 (N/A)	No	Commercial (trial version available)	Closed	Yes	No	Yes	Yes	Native	Motion data EMG Force plate	2D / 3D	Offline	Yes	Yes	No	No
MSMS [MSMS]	2.0 (2012.02)	Yes [Khachani'97]	Free	Closed	Yes	Yes	Yes	Yes	External	-	3D	Both	Yes	Yes	Yes	Yes
ODIN [ODIN]	1.0 (2011.10)	No	Commercial	Open	Yes	Yes	Yes	Yes	External	Motion data EMG Force plate	3D	Both	Yes	Yes	No	No
OpenSim [OpenSim]	2.4.0 (2011.10)	Yes [Delp'07]	Free	Open	Yes	No	Yes	Yes	Absent	Motion data EMG Force plate	3D	Offline	Yes	Yes	Yes	Yes
SIMI motion [SIMI]	7.2 (2005.05)	No	Commercial	Closed	Yes	Yes	Yes	Yes	Native	Motion data EMG Force plate	2D / 3D	Offline	Yes	No	Yes	No
SIMM [SIMM]	6.01 (2011.06)	Yes	Commercial	Closed	Yes	No	Yes	Yes	Native	Motion data EMG Force plate	3D	Both	Yes	Yes	Yes	Yes
Templo [Templo]	5.1 (2012.03)	No	Commercial	Closed	Yes	Yes	Yes	No	Native	EMG Force plate	2D / 3D	Offline	Yes	Yes	No	No
Visual3D [Visual3D]	4.95 (N/A)	Yes [Kepple'91]	Commercial	Open	Yes	Yes	Yes	Yes	External	Motion data EMG Force plate	2D / 3D	Both	Yes	Yes	No	Yes

Table 1: Human Motion Analysis and Simulation Tools.