Chapter 12
Human Motion Analysis and Simulation Tools: A Survey

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ABSTRACT

Computational systems to identify objects represented in image sequences and tracking their motion in a fully automatic manner, enabling a detailed analysis of the involved motion and its simulation are extremely relevant in several fields of our society. In particular, the analysis and simulation of the human motion has a wide spectrum of relevant applications with a manifest social and economic impact. In fact, usage of human motion data is fundamental in a broad number of domains (e.g.: sports, rehabilitation, robotics, surveillance, gesture-based user interfaces, etc.). Consequently, many relevant engineering software applications have been developed with the purpose of analyzing and/or simulating the human motion. This chapter presents a detailed, broad and up to date survey on motion simulation and/or analysis software packages that have been developed either by the scientific community or commercial entities. Moreover, a main contribution of this chapter is an effective framework to classify and compare motion simulation and analysis tools.

INTRODUCTION

Systems that are able to identify objects represented in image sequences and to track their motion in a fully automatic manner, allowing a detailed analysis of the involved motion and its simulation, are important in several fields of our society. Concerning in particular the study and simulation of human motion, these systems have a wide spectrum of relevant potential applications, with a noticeable social and economic impact.

Despite the fact that human motion analysis and simulation is not a recent topic of research, computer vision-based human motion analysis and simulation is a very active multidisciplinary research topic, where a great amount of research effort is being carried out. During recent years, relevant instances of attention devoted to this topic are the number of published surveys, special journal issues, workshops and seminars directly related to this field (J. K. Aggarwal & Ryoo, 2011; J. K. Aggarwal, Cai, Liao, & Sabata, 1994; J. K. Aggarwal & Cai, 1999; Gavrila, 1999; Ke et al., 2013; Liu, Jia, & Zhu, 2009; Moeslund & Granum, 2001; Moeslund, Hilton, & Krüger, 2006; Poppe, 2010; Turaga, Chellappa, Subrahmanian, & Udrea, 2008; J. J. Wang & Singh, 2003; L. Wang, Hu, & Tan, 2003; Zhou & Hu, 2008).

The interest on this field of research is not surprising, and owes to a number of factors. In part, from a technical point of view, it is due to its highly interdisciplinary nature, combining knowledge from several domains (e.g.: computer graphics, biomechanics, computer vision, machine learning, among others), where there are still many problems to solve. On the other hand, it is due to the massive availability of low-cost sensory hardware with significantly better performances (such as video cameras and depth sensors), due to the emergence of faster computational platforms (such as multi-core systems and those taking benefits from the graphics processing unit for general purpose computing) and the advances in computer vision algorithms, in addition to a global demand for a wide spectrum of relevant real world and potential applications.

Throughout this chapter we present a detailed, broad and up to date survey on motion simulation and/or analysis software packages that have been developed with the purpose of analyzing and/or simulate in detail the biomechanics of human motion. Beyond the comprehensive listing of these tools, the main contribution of this chapter is a proposed effective framework to classify and compare motion simulation and analysis tools. To accomplish the aforementioned purpose we have identified and described a set of relevant features. As the main outcome, the surveyed tools were classified in respect to the proposed framework and a comparative overview of all the analyzed tools is summarized.

HISTORICAL PERSPECTIVE

Since the early days of science, the topic of motion analysis aroused a great interest in many researchers with different backgrounds, interests and motivations, like Hippocrates (460-370 BC), Aristotle (384-322 BC), Galen (129-217), Vesalius (1514-1564) and Galileo (1564-1642), among others. Leonardo Da Vinci (1452-1519) was the first to accurately depict the human adult spinal posture with its curvatures, articulations and number of vertebrae. He was particularly interested in the structure of the human body and how it relates to performance and also how to estimate its center of gravity and its balance. In his sketchbooks he stated that

… is indispensable for a painter to become totally familiar with the anatomy of nerves, bones, muscles, and sinews, such that he understands for their various motions and stresses, which sinews or which muscle causes a particular motion.

Giovanni Alfonso Borelli (1608-1679) also gave his contribute by clarifying the muscular movement and the body dynamics. In his publications (*De Motu Animalium I* and *De Motu Animalium II*) he applied into the biological world the geometric analysis used by Galileo in the field of mechanics. He used the Geometry to describe some movements, like walking, running or jumping, and described the muscle contraction. Borelli also figured out the forces required for equilibrium in various joints of the human body and also determined the position of the human center of gravity. Figure 1 illustrates some of his drawings that were conceived during these studies.

During the 19th century the German Weber brothers (Wilhelm and Ernst) analyzed the human locomotion and hypothesized about the human gait, resulting in the publication of a book (Weber & Weber, 1837), which was later translated to “Mechanics of the Human Walking Apparatus”(Weber, Weber, Maquet, & Furlong, 1992). They were the first who studied the path of the center of mass during movement.

Later, the French scientist Etienne-Jules Marey (1830-1904), during his motion studies, used a cart of transport to track a moving subject. On top of the car he installed a special camera (the *chronophotographic gun*) that he designed, capable of taking 12 consecutive frames per second (see Figure 2), where the several phases of the motion were stored in the same picture. With this technique it became possible to acquire image sequences that revealed details of human and animal locomotion, that were not noticeable by watching the movement with the *naked eye*. Using these pictures Marey studied the movement of humans and other animals - people used to dress in tight black suits and white lines marking them to better track the movements of different body parts in each phase. His research on how to acquire image sequences and afterwards how to present them helped the emerging field of cinematography, leading Marey to be known as a pioneer of photography, and an influential pioneer of the history of cinema.

Inspired by the photographic work of Marey, Eadweard Muybridge (1830-1904) proposed a new solution for recording fast motion. He became known as the pioneer in motion capturing with his experiments called “Animal Locomotion”. He used an array of 12 cameras to photograph a galloping horse in a sequence of shots. The cameras were controlled by an electric mechanism that operate the cameras’ special shutters, and a set of wires were laid underground along the track, so that the shutter of each camera was released as the wheels of the horse carriage made contact. Later he designed the *zoopraxiscope projector* - a device for projecting the recorded series of images from rotating glass disks in rapid succession to give the impression of motion. He also applied this technique to human movement studies for different categories of locomotion, compiling the results in the book entitled “The Human Figure in Motion” (Muybridge & Taft, 1955). One example of this type of experiments is shown in Figure 3, where we can see a man lifting a trunk.

More recently, during the 20th century, many other researchers have contributed to an increasing knowledge of human biomechanics (Baker, 2007; Lu & Chang, 2012): John V. Basmajian (1921-2008) expanded electromyography techniques and understanding of muscle function; David A. Winter (1930 2012) 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.

HUMAN MOTION APPLICATION AREAS

The number of potential applications that somehow make use of the human motion is quite vast. In fact, the human motion analysis, as well as the computer simulation of several human capabilities, have shown to be essential in many different types of applications, including: (i) sports, in order to improve athletes’ performances; (ii) ergonomic studies, to assess operating conditions for comfort and efficiency

Figure 1. Some Borelli's drawings conceived during his biomechanical studies
(Thurston, 1999) (left).

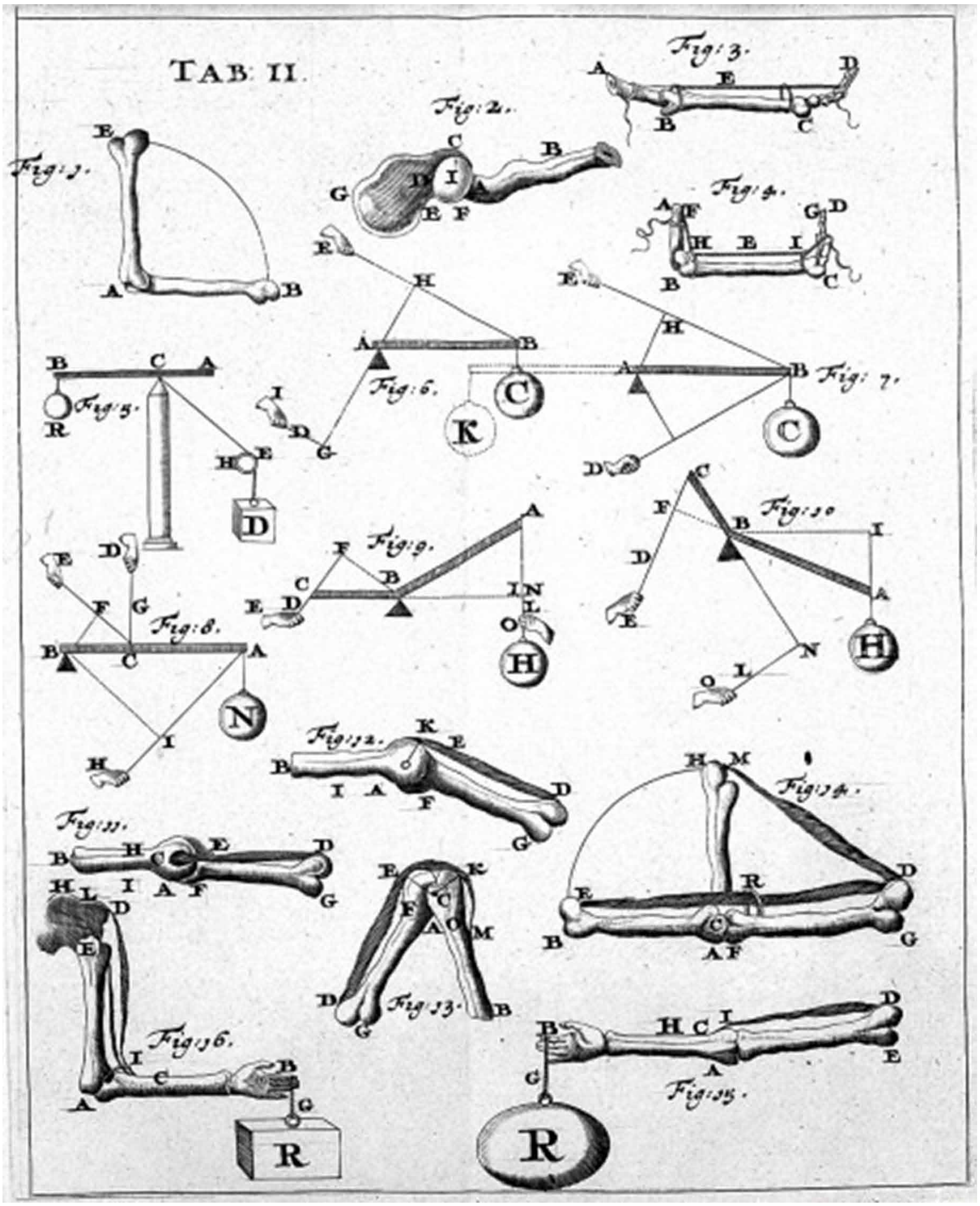
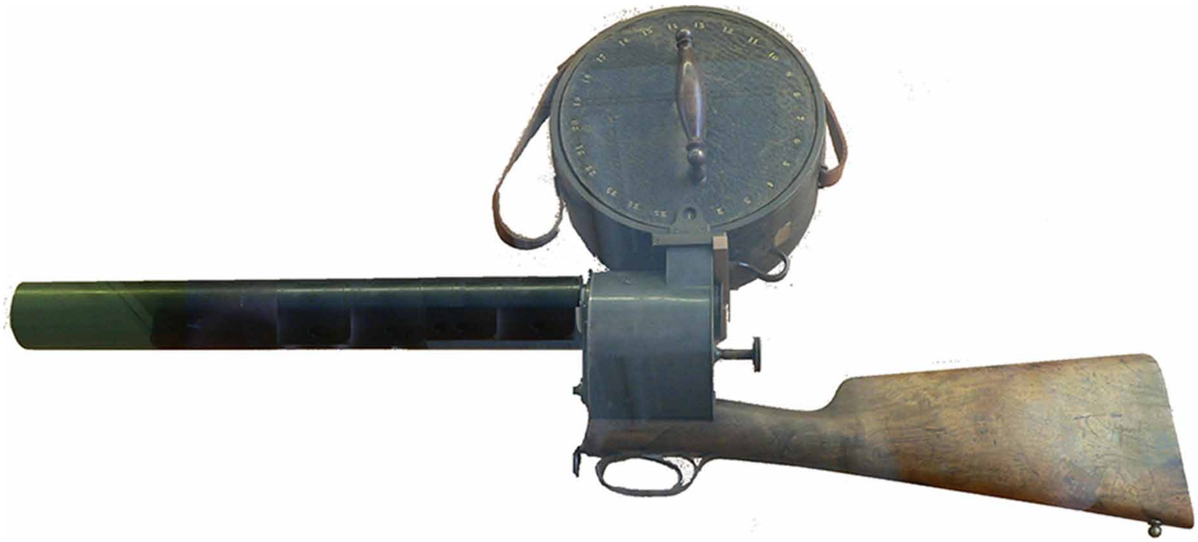


Figure 2. Marey's chronophotographic gun, which was capable of taking 12 consecutive frames per second.

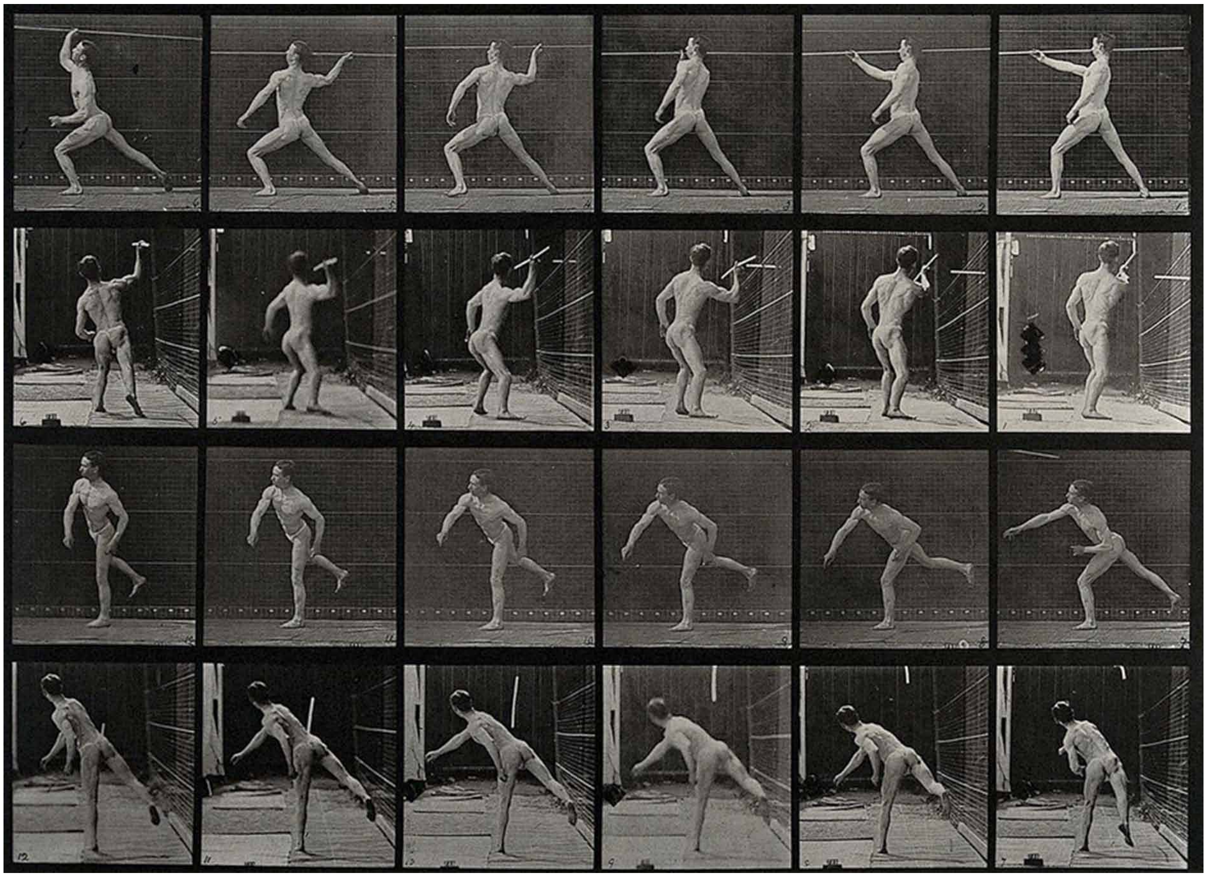


in different aspects of human body interaction with the environment; (iii) health, to detect movement abnormalities; (iv) gesture-driven user interfaces, to develop intuitive human-machine interfaces; (v) smart surveillance, to automatically monitor people and identify abnormal movements; (vi) virtual reality, to animate virtual characters; (vii) design and car industry, to develop ergonomically safe environments, products and devices; and (viii) video annotation, to accurately classify and retrieve videos. The previous examples demonstrate seamlessly the social and economical impact of human motion research results. In the following paragraphs, some of the current and potential applications are briefly described.

Sports

The biomechanical analysis of movements, as well as its simulation, has become crucial in the field of sports, resulting in a powerful tool that athletes and their coaches have acknowledged and adopted on their training practices. The usefulness of these tools on their daily activity is clear, either as a training tool, where the resulting knowledge about efficiency of certain techniques can provide a basis for future recommendations for training exercises; or as a tool to improve athletes' performances – they can observe and compare their techniques with a particular professional athlete who executes the same movement and consequently correct and eventually improve their performances; or even as a tool for risk assessment – the lack of proper technical guidance often leads to muscle and joint problems. Many scientific work has been presented with these goals in mind: Gittoes and Irwin (2012), for example, conducted biomechanical approaches to understand the potentially injurious demands of gymnastic-style impact landings; Fukuchi & Duarte (2008), intended to better understand the differences between young adult runners and elderly runners by comparing their three-dimensional lower extremity running kinematics; Panagiotakis et al. (2006) described an automatic human motion analysis and action recognition scheme that was tested on athletics videos; and Syamsuddin and Kwon (2011) described how to perform dynamic simulations of real world baseball data to support real batting practice in a virtual world.

Figure 3. A man lifting a trunk session recorded by Muybridge
(Wellcome Library, London - CC BY 4.0).



Computer systems can also support coaching activities of teams, performed before and after competitions. For example, Beetz et al. (2005) presented a system capable of acquiring models of player skills, infer action-selection criteria, and then determine player and team strengths and weaknesses; Santiago et al. (2013) proposed a vision-based system that can extract teams' accurate statistics and performance data from both practice sessions and games.

Health

Clinical gait analysis is commonly considered as the measurement, processing and systematic interpretation of biomechanical parameters that characterize the human locomotion (Davis, 1997). Traditionally, human gait has been studied subjectively by visual observations, which is the simplest and also most informal way to analyze it. This method is the therapist's primary clinical tool used for describing the quality of a patient's walking pattern, and it still continues to be the common practice in most physician offices, which are not equipped with devices and systems that are required for an advanced and detailed analysis.

Nevertheless, this kind of assessment can be extremely unreliable, considering that every time a patient is being observed, the expected outcome can only be a general impression of his/her motion. Yet, eventually for some types of diagnostics, this method may be adequate. As an intent to systematize and maximize the reliability of this kind of evaluation, some studies were conducted (Eastlack, Arvidson, Snyder-Mackler, Danoff, & McGarvey, 1991; Krebs, Edelstein, & Fishman, 1985) promoting, for example, the usage of scales to rate the gait. Even so, an objective and "formal" assessment can only be achieved by performing a careful examination of the gait, which implies the acquisition and the processing of basic components of motion, as well as the ability to clinically interpret this information (Sutherland, 2005).

Combining advanced measurement technology and biomechanical modeling, human gait can be described in both quantitative and dynamic terms the movement of the body and its limbs during motion. Clinical trials and scientific studies are conducted to achieve a better understanding of the human motion and to develop more effective methods to comprehend how neuromuscular impairments affect motion, providing a scientific basis for treatment (Audu, To, Kobetic, & Triolo, 2010; Yavorskii, Sologubov, & Nemkova, 2003). Some relevant scientific work can be found in (Ambrósio & Abrantes, 2007; Lu & Chang, 2012; Mündermann, Corazza, & Andriacchi, 2006). For instance, Simsik, Majerník, Galajdová, & Zelinsky (2005) conducted a study of *spondylolisthesis* using video motion analysis; Chia, Licari, Guelfi, & Reid (2013) made a comparison of running kinematics and kinetics in children with and without developmental coordination disorder; and in the work presented by (Yavorskii et al., 2003), which consisted in analyzing the gait in patients with different forms of infantile cerebral paralysis. In cases of clinical procedures, like surgery interventions, or rehabilitation procedures the study of the human motion can assist physicians in the decision-making of the surgery and during the follow-up period, or in physiotherapy, where it can aid to decide which type of therapeutic should be applied, as well as to evaluate the post-treatment (Tseh, Caputo, & Morgan, 2008).

Gesture-Driven User Interfaces

The recognition of gestures using computer vision techniques can be seen as a form of artificial intelligence, enabling computers to understand the human body language. The recognized gestures or pose parameters are then used to control something, either for digital games purposes, interactive play-spaces, smart home environments, digital publicity, virtual reality or other application scenarios. One of the major goals of this field of research is to develop intuitive human-machine interfaces, reducing, or eventually eliminating the need of input devices such as joysticks, mice and keyboards, allowing users to give instructions to the computer mainly through gestures, poses or facial expressions, without having to wear any special equipment, like data gloves or special suits, or even to attach any devices to their body. Several examples of applications based on gestures have been presented in the literature, ranging from gaming and entertainment, sign language recognition, movement assessment, senior home monitoring, device remote control, and human-robot interaction, to name a few.

Computer games are becoming highly disseminated and play an important role in the lives of many people. The advent of new interfaces for interacting with computers can have a positive impact on their usage, promoting a non-sedentary lifestyle while playing. The work presented by Höysniemi, Hämäläinen, Turkki, & Rouvi (2005) is a good example of a game application with a gesture-based interface, where the player needs to exercise in order to make the avatar move: the player needs to flap his hands to make the game character fly, and the player needs to shout for the game character breathe fire. Another example of a gesture recognition application is presented by the Microsoft Research Asia. They have developed an application for American and Chinese Sign Language visual recognition and communication using the Kinect sensor (Chai et al., 2013). The system has two modes: the translation mode, in which the system translates the sign language into text or speech for non-sign users; and the second, the communications mode, which translates verbal language into sign through the use of an onscreen avatar. Also an interesting field of application relies on human-robot interaction, with many published work: (Fong, Nourbakhsh, & Dautenhahn, 2003; Goodrich & Schultz, 2007; Trigueiros, Ribeiro, & Reis, 2013). A noticeable pioneer example is the work presented by Kortenkamp et al. (1996) where the authors developed a real-time, three-dimensional gesture recognition system, capable of recognizing six distinct gestures made by a human in an unaltered environment. For smart home environments, where the main goal is to improve the interaction with home devices, Chae, Lee, Han, & Yang (2013) presented a method to detect deactivation events based on a vision approach involving face detection and motion detection for a smart TV, enabling a sleep mode detection, allowing significant better performances of power management and green computing. Another interesting work is presented in (Chen, Mummert, Pillai, Hauptmann, & Sukthankar, 2010), where the authors presented a method to recognize human gestures, but now to control TV operations (change channel, change volume, etc.).

Smart Surveillance

In our days, issues like security of private and public areas, including shopping malls, airports, subways, train stations, among others, are extremely sensitive and critical. For that reason, security systems whose main focus is to automatically monitor people and identify abnormal movements are crucial for society. One application scenario is for intrusion detection, where the positioning of individual body parts is irrelevant, and because of that the entire body is tracked, analyzed as a single object. Two examples of smart surveillance systems with this approach are described in (S.-R. Ke et al., 2013) and (Wiliem, Madasu, Boles, & Yarlagadda, 2012). In the first work, the aim is to automatically detect intruders or abnormal activities and then alert the related authority of potential criminal or dangerous behaviors, while in the second it is proposed an automatic system for detection of human suspicious movements.

More recent surveillance applications are contemplating the analysis of actions, activities, and behaviors - both for crowds and individuals (Moeslund et al., 2006). The acquisition of motion and/or body parameters including pose, orientation and joint angles can result as biometric cues for personal identification, categorizing personal styles of the walking movement (Boyd & Little, 2005; Liu et al., 2009; L. Wang, Tan, Ning, & Hu, 2003; J. Zhang, Pu, Chen, & Fleischer, 2010). Grieve & Gear (1966) and Murray, Drought, & Kory (1964), carried some initial studies in order to identify unique characteristics of the walking movement. They demonstrated that there is a high correlation between step length and height of a person, and that the step length can be different between subjects if there are differences in height. Gait can also be used for gender recognition. Yu, Tan, Huang, Jia, & Wu (2009) demonstrated that gait-based gender classification is feasible in controlled environments. A correct gender classification can be used in the advertising billboards, where different gender-specific advertisements can be played, or at the entrance of a restroom, in order to detect if a person is correctly using the gender-specific restroom (Chang & Wu, 2010).

Virtual Reality

Animated characters, either as autonomous agents or as avatars in virtual worlds are different versions of simulated humanoids that use human motion. They can be seen in non-interactive content such as movies or in interactive applications like videogames and virtual worlds (Cavazza, Earnshaw, Magnenat-

Thalmann, & Thalmann, 1998; Egges, Kshirsagar, Magnenat-thalmann, & Thalmann, 2003; Hemp, 2006). The perception of human actions improves considerably the human computer interaction, as showed in (Nguyen et al., 2005) where the authors presented a real-time system for capturing humans in 3D, creating an avatar to reproduce the gestures of the player and placing the avatar into a mixed reality game environment. The user, looking through a head-mounted display with camera in front, pointing at a marker, can see the 3D image of this subject overlaid onto a mixed reality scene.

Design and Car Industry

Design engineers often struggle to understand true system performance until very late in the design process leading to rework and design changes, which are riskier, time consuming and more costly. A timely and accurate analysis proves to be essential within design processes, including the development of ergonomically safe environments, products and devices (e.g.: prostheses, sports equipment, workspaces and cars). For example, Mavrikios et al. (2006) presented an ergonomic study of the human posture while stepping into a car. Human models were developed for predicting a realistic accessibility motion, having as input human anthropometrics, and the output data of those models were either motion trajectories or joint angles of critical body segments that could be further incorporated into human modeling software tools to drive digital human models during product ergonomic evaluation, providing data on potential injury risk and postural analysis. Another example lies in traffic safety as the systems to automatically detect sleep onset in fatigued drivers presented by Albu et al. (2008) and Kircher et al. (2009).

Video Annotation

The “democratization” of technology guaranteed the access to digital devices and consequently increased the amount of multimedia contents produced, raising significantly the size of the multimedia repositories. Simultaneously, several applications arise needing to accurately access the unstructured data stored on those repositories. An example application is to find particular events in videos such as gestures (e.g.: handshakes), or typical dance moves in music videos (Poppe, 2010). In order to facilitate an efficient access and an accurate search to those contents, several solutions for an automatic video annotation have been developed. An example is presented in (Panagiotakis, Ramasso, Tziritas, Rombaut, & Pellerin, 2008) where it is proposed a method to classify sport videos as team sports or as individual sports, or in (Y. Ke, Sukthankar, & Hebert, 2007) where it is proposed a method that can detect a wide range of actions in video, as demonstrated by results on a long tennis match video.

HUMAN MOTION ANALYSIS AND SIMULATION

Given the range of human motion related applications, there are numerous techniques that can be used to capture the human motion, to process the resulting data and also to simulate it, each one with its own strengths and weaknesses. For each application scenario it is possible to select the techniques that best fit its constraints and specific needs (e.g.: budget, scene conditions, available equipment and software, etc.).

The techniques behind capturing the motion data can be classified as optical and non-optical. Non-optical systems, or sensor-based systems, include the inertial, magnetic and mechanical motion capture techniques, which involve somehow the modification of the clothes of the subject that is being tracked in order to contain sensors. These systems have the disadvantage of being intrusive, which can affect the system's performance and limit its application. Optical-based systems include techniques based on special markers attached to the human body (active detection and passive detection), and based on detection without markers. These systems utilize data captured from one or more image sensors (e.g.: video cameras) to triangulate the 3D position of a subject. Optical-based systems with an active detection requires that certain devices must be placed in the subjects (usually LED markers) and in the surrounding spaces which emit and receive signals, respectively. The active detection is often used under controlled environments, allowing a simpler processing. For instance, in the movie industry the techniques most commonly used for motion capture require expensive multi-camera and invasive marker systems, which involve a careful calibration and highly controlled laboratory conditions. On the other hand, optical-based systems with a passive detection are based on natural sources of signal, (e.g.: visible light or other electromagnetic wavelengths), and are illuminated using infrared lights mounted on the cameras (Moeslund & Granum, 2001). More recent systems are also able to generate accurate data by tracking surface features identified dynamically for each particular subject, exempting, this way, the use of markers. These systems, also known as optical-based *markerless* systems have the advantage of being totally non-intrusive.

Human Motion Analysis

The analysis of human actions is the observation and the definition of human movements. It comprises the acquisition of the human motion during a certain period of time and afterwards its assessment. Computer-based motion analysis plays almost the same role as an ergonomist, a physician, a trainer or any other specialist that objectively and quickly evaluates the motion. In order to accomplish this objective, motion data needs to be segmented and then, the tracked motion information needs to be mapped into motion descriptions. Higher level processing of this data can be carried out for human activity recognition, motion reconstruction, pose estimation, event detection, biomechanical study of motion, etc. Since this chapter focus on human motion, its analysis encompasses kinematic and kinetic studies (L. Wang, Tan, et al., 2003). The kinematics is the measurement of the movement, i.e., is the process of measuring the kinematic quantities used to describe motion (e.g.: trajectories, velocities and accelerations), while kinetics is the study of the motion and its causes. Kinetic measurements are largely influenced by the forces acting between the foot and the ground, which are commonly measured by an instrumented section of the floor known as a "force platform". Human motion analysis involves the use of "inverse dynamics" to calculate joint moments and powers, using the limb motion from a kinematic system, and ground reaction force from a force platform as input data. Often electromyography can be combined to provide complete information.

Human Motion Simulation

Computer simulation of several human capabilities has shown to be helpful in many research and development activities, as seen in a previous section of this chapter, offering many advantages opposed to experiments: it's risk free; can help to reduce the number of physical prototypes, and consequently reducing expenses; can speed up the design process, enabling time compression; and sometimes can result in a training tool (Garcia, Doblare, & Cegonino, 2002). The usage of simulations can solve complex engineering problems, and have the potential to revolutionize experimentally based decision-making.

Human motion simulation is used to analyze walking dynamics, simulate surgical procedures, analyze joint loads and to design medical devices. Concerning motion dynamics, experiments do provide important but a limited understanding. It is possible to measure some quantities, such as muscle activities and ground reaction forces, however simulations complement these measurements with estimates of other important variables, such as muscle and joint forces. Simulations also allow us to establish cause-and-effect relationships giving insights into muscle function. Another interesting feature about simulations is the potential to perform "what if" studies to test hypotheses, predict functional outcomes, and identify emergent behaviors (Reinbolt, Seth, & Delp, 2011).

An example of a simulation of the human locomotion is presented in the work from Pronost & Dumont (2007). The authors proposed a method for evaluating the dynamical correctness of retargeted and interpolated motions generated by an editing method. This editing method adapts the motion to a new character and to locomotors parameters thanks to a morphological retargeting and kinematical interpolations in a motion database. An inverse dynamic analysis was used to study the physical accuracy of the adapted motions, by computing the resulting forces and torques at joints. The synthesized motion is very close to the original motion.

SELECTED TOOLS

This work surveys the state of the art in respect to automated tools in human motion analysis and simulation. To accomplish this study we made a comprehensive research to select the most cited tools within the literature. Scientific literature, namely articles and papers, from several journals and conference proceedings, supported this selection. Complimentarily, we have also consulted the official web pages of research laboratories whose focus is somehow related to motion analysis and simulation. Afterwards, we have created a questionnaire that was sent to the commercial departments, or in some cases, directly to the author(s) of each of the applications, with the purpose to confirm and validate the information about the tools.

Next we briefly present each of the twenty-five studied tools, sorted alphabetically. The tools marked with a "*"are those for which the authors/companies have answered to the questionnaire: Adams*, AnimatLab, AnyBody Modeling System, BTS Smart DX, Dartfish, DMAS6 Motion Capture Suite, Hu-M-An, K2Analyzer, KAPro, Kinovea*, Kwon3D XP*, MaxPRO*, MaxTRAQ*, Mokka*, Motion Analysis Tools*, MotionGenesis Kane*, MSMS, MVN Studio*, ODIN, OpenSim*, SIMI motion, SIMM, Templo*, ViconMotus 2D/3D*, Visual3D* and WINanalyze*.

Adams* (http://www.mscsoftware.com/product/adams)

Adams (Automatic Dynamic Analysis of Mechanical Systems) is a commercial solution from MacNeal-Schwendler Corporation (MSC) with a closed architecture, whose latest version is the v.2014, from the same year, and it is available for Windows and Linux. It has its own library of models, and it is possible to create new models or to edit existing ones. The motion data that is applied to the models must be acquired with an external motion capture system, and both analysis and simulations of the human motion are done in three-dimensions.

Instances of relevant work that have referred to the surveyed tool: Al Nazer et al., (2008) and Vignais & Marin, (2014).

AnimatLab (http://www.animatlab.com)

AnimatLab is an open-source tool from NeuroRobotic Technologies, written to provide a general simulator for neuromechanical processes of skeletal animals. The most recent version is the 2.1.2, from 2014, with a standard version (free) and a professional version (not free), for Windows and Linux. AnimatLab enables a computational model to be constructed and edited, subject to the laws of physics, responding to external and internal signals, generating its movement. It has a modular architecture, which makes it extensible via its pluggable C++ based interface.

Instances of relevant work that have referred to the surveyed tool: Cofer et al., (2010) and Edwards, (2010).

AnyBody Modeling System (http://www.anybodytech.com)

The AnyBody Modeling System tool was initially developed at the Aalborg University, Denmark (Damsgaard, Rasmussen, Christensen, Surma, & Zee, 2001) and is currently commercially available at AnyBody Technology. AnyBody latest version is 6.0.4, available to the Windows platform, however a cross-platform version of the system is being considered. It allows a three-dimensional analysis and simulation of the mechanics of the human body interacting with its environment. The environment is defined in terms of external forces and boundary conditions, and the user may impose any kind of posture or motion for the human body, either from scratch (using the tool's modeling language: AnyScript) or from a set of recorded motion data.

Instances of relevant work that have referred to the surveyed tool: Bajelan & Azghani, (2014) and Farahani, Bertucci, Andersen, Zee, & Rasmussen, (2014).

BTS SMART (http://www.btsbioengineering.com)

BTS SMART has a set of software solutions devoted to the assessment of human movement. These commercial tools are developed by BTS Bioengineering Corporation (Italy), and their latest version was released in 2010, with no trial version available. Motion data is acquired with a native motion capture system, and its analysis is computed in three dimensions, either in real-time or offline.

Instances of relevant work that have referred to the surveyed tool: Bacchini, Cademartiri, & Soncini, (2009) and Gokeler et al., (2013).

Dartfish (http://www.dartfish.com)

Dartfish, SA (Switzerland), founded as InMotion Technologies, Ltd., developed Dartfish, a two-dimensional video analysis software, currently in version 7 - release 9, from 2014. This tool enables biomechanical observation, comparison and quantitative measurement of time, distance, angle and position. The company also provides Dartfish.tv, a video casting solution that empowers to produce and share videos. No simulation is available.

Instances of relevant work that have referred to the surveyed tool: Eltoukhy, Asfour, Thompson, & Latta, (2012) and Khadilkar et al., (2014).

DMAS: Digital Motion Analysis Suite (http://www.mi-as.com)

The DMAS (Digital Motion Analysis Suite) is comprised of modular components and it's developed by Motion Imaging Corporation (USA). This tool is capable of acquiring video data from multiple cameras as well as synchronized analog/digital data, allowing a real-time analysis. Recorded video and data are simultaneously captured, calculated, synchronized and displayed in real time. It has a modular architecture, which makes it extensible via internal scripting or via its C++ SDK. The latest version is from 2005 and there is no trial version available. It contains an editor tool for constructing flexible and editable models.

Instance of relevant work that has referred to the surveyed tool: Lujan, Lake, Plaizier, Ellis, & Weiss, (2005).

Hu-M-An (http://www.hma-tech.com)

The HMA Technology (Canada) developed Hu-M-An (also known as Ehuman), which is a video-based 2D and 3D human movement analysis software. It is also presented as a platform for teaching or learning movement mechanics. Hu-M-An is a commercial product, currently on version 6, with a trial version available. The analysis and simulation of the human motion are computed in both dimensions, but not in real-time. The tool offers the capability of creating new models and to edit existing ones.

Instance of relevant work that has referred to the surveyed tool: Carvalho et al., (2007).

KA Pro: Kinematic Analysis Software (http://userwww.sfsu.edu/biomech/ForFaculty.htm)

The Kinematic Analysis Software suite (San Francisco State University, USA), currently on version 7.1, is freely available only for faculty members. The suite includes the components of a complete undergraduate biomechanics curriculum, namely a biomechanics electronic textbook (BHMViewer), a full-featured video data analysis software suite (KAPro), a detailed computer-based laboratory curriculum (BLCViewer), an advanced undergraduate biomechanics textbook (QHMViewer), and an extensive Movement Library. KAPro video analysis program can be used to prepare and digitize trials of video files, and the KA2D and KA3D programs are used to analyze the resulting kinematic data, providing access to linear and angular kinematic data for all body points and segments, and kinematic level analysis of three dimensional data. Finally, the JtCalc program provides measures of ground reaction force, leg joint torque and joint muscle power. No simulation is available.

Instances of relevant work that have referred to the surveyed tool: Knudson & Morrison, (2002) and Knudson, 2007; Radoslav et al., (2008).

Kinovea* (http://www.kinovea.org)

Kinovea is an open-source, freely available, video player tool that can be used to measure distances and times manually or to use semi-automated tracking to follow points and check live values or trajectories. The motion analysis is computed offline in two-dimension, and motion simulation is not available. Its latest version is the 0.8.23, from 2014, and it is available for Windows.

Instances of relevant work that have referred to the surveyed tool: Bini & Carpes, (2014) and Guzmán-Valdivia, Blanco-Ortega, Oliver-Salazar, & Carrera-Escobedo, (2013).

KWON3D XP* (http://www.kwon3d.com)

Kwon3D XP is a motion analysis software package that was developed in 1990 by VISOL Inc. (Korea). Its latest version is the 4.1, released in 2004, with a trial version available, for Windows. It has a set of models that can be used and edited for the motion analysis, which can be done in both dimensions, occurring offline. The motion data can be imported or acquired with a native non-optical based motion capture system. No simulation is available.

Instances of relevant work that have referred to the surveyed tool: Lambert, Kwon, & Kwon, (2009) and Yoon, Ryu, & Kwon, (2007).

MaxPRO and MaxTRAQ* (http://www.innovision-systems.com)

Innovision Systems, Inc. (USA) has developed a set of tools, namely MaxPRO (version 1.4.0.1, from 2010) and MaxTRAQ (version 2.13, from 2009), both available for Windows, for motion analysis. Both applications have an open architecture, and the analysis of the motion is computed in three-dimensions, occurring offline. The motion data is acquired with a native system, optical-based with passive markers, using multi cameras. No simulation is available.

Mokka: Motion Kinematic and Kinetic Analyzer* (http://b-tk.googlecode.com)

Mokka is a standalone application of the Biomechanical Toolkit, an open-source framework to visualize and process biomechanical data (Barre & Armand, 2014). It is cross-platform, freely available, with an open architecture, whose latest version is the 0.6.2, from 2013. The motion analysis occurs offline, in two or three dimensions and no simulation is available.

Instances of relevant work that have referred to the surveyed tool: Attias et al., (2014) and Punt, Ziltener, Laidet, Armand, & Allet, (2014).

MAT: Motion Analysis Tools* (http://www.irrd.ca/cag/mat)

MAT (Motion Analysis Tools) is a Windows based program for taking measurements from digital video. It has a closed architecture and its latest version (v2.8) was released in 2009. The tool enables the creation of new models to be used in the two-dimensional analysis of the motion, which occurs offline. No simulation is available.

MotionGenesis Kane* (http://www.motiongenesis.com)

MotionGenesis Kane is a symbolic manipulator for forces and motion, which incorporates Newtonian physics, simulating the motion of biomechanical systems. This commercial product has an open architecture that can be used for a real-time, three-dimensional analysis and simulation of the human motion. Its latest version is 5.5, from 2014, available for Windows, MacOS and Linux.

Instance of relevant work that have referred to the surveyed tool: McKay & Ting, (2012).

MSMS: Musculoskeletal Modeling Software (http://mddf.usc.edu)

MSMS is a freely available software application for modeling and simulating neural prostheses systems. It was developed at the University of South California (USA) (Khachani, Davoodi, & Loeb, 2008) and its latest version is the 2.2, released in 2012. This application can be used to model and simulate human and prosthetic limbs, as well as the task environment where they operate in. It allows users to build new musculoskeletal models and edit their properties, or to import existing musculoskeletal models from 3rd party applications, like OpenSim or SolidWorks. Motion simulations and analysis are computed in three-dimensions, in real-time.

Instance of relevant work that have referred to the surveyed tool: Chauhan & Vyas, (2013).

MVN Studio BIOMECH* (http://www.xsens.com/functions/human-motion-measurement)

MVN Studio BIOMECH is a variant of the MVN Studio, which is an Xsens Technologies (The Netherlands) software tool devoted to motion analysis. This Windows based commercial tool, in version 4.0 from 2014, enables three-dimensional and real-time analysis and simulation of the human motion, gathering the motion data from a native motion capture system.

Instance of relevant work that have referred to the surveyed tool: J.-T. Zhang, Novak, Brouwer, & Li, (2013).

ODIN (http://www.codamotion.com)

ODIN is a commercial software application developed by Charnwood Dynamics Ltd. (United Kingdom). It has an open architecture and the most recent version is the v1.01, from 2013, available for Windows. Users can synchronize their movement analysis data with data from high-speed video cameras, force plates, EMG systems and other third-party hardware. No simulation is available.

Instances of relevant work that have referred to the surveyed tool: Menant, Steele, Menz, Munro, & Lord, (2009).

OpenSim* (http://opensim.stanford.edu)

OpenSim is a freely available, open-source software system that allows users to develop models of musculoskeletal structures, exchange, and analyze them and create dynamic simulations of a wide variety of movements. Users can extend OpenSim by writing their own plug-ins for analysis or control, or to represent neuromusculoskeletal elements. In a graphical user interface, users are able to access a suite of high-level tools for viewing models, editing muscles, plotting results, and other functions. OpenSim is an academic project that began at the Stanford University (USA) and the latest version is the 3.2, released in 2014.

Instances of relevant work that have referred to the surveyed tool: Delp et al., (2007)

SIMI Motion (http://www.simi.com)

SIMI Motion is commercialized by Simi Reality Motion Systems (Germany). It provides a platform for automatic tracking and subsequent manual assignment of passive markers and for a real-time movement analysis. It is possible to integrate and synchronize data from a number of external devices (e.g.: EMG, EEG, ECG, force plates, pressure measuring). Currently on version 8.5, released in 2012, it is available for Windows. No simulation is available.

Instance of relevant work that has referred to the surveyed tool: Wangerin, Schmitt, Stapelfeldt, & Gollhofer, (2007).

SIMM: Software for Interactive Musculoskeletal Modeling (http://www.musculographics.com)

SIMM (Software for Interactive Musculoskeletal Modeling) enables the analysis of a musculoskeletal model. Users can explore the effects of changing musculoskeletal geometry and other model parameters on muscle forces and joint moments. The dynamics module allows users to perform forward and inverse dynamic simulations on musculoskeletal models. The software is developed by MusculoGraphics, Inc. (USA), and the most recent version is the 7.0, presented in 2013. It is available a SIMM tryout version under a registration process.

Instance of relevant work that has referred to the surveyed tool: Bachynskyi, Oulasvirta, Palmas, & Weinkauf, (2014).

Templo* (http://www.contemplas.de)

Contemplas GmbH (Germany) developed Templo, a two dimensional video-based analysis system, currently in version 8.0 from 2014. This application includes several modules, each one with a specific usage within motion analysis, and can be extended with additional modules, enabling the integration of various hardware components (e.g.: high-speed systems, force plates, pressure plates, EMG). No simulation is available.

Instance of relevant work that has referred to the surveyed tool: Katashev, Shishlova, & Vendina, (2014).

Vicon Motus 2D and 3D* (http://www.contemplas.de)

Contemplas GmbH also develops and distributes Vicon Motus 2D and 3D: two programs used for a biomechanical analysis. These commercial applications, currently in version 10 from 2014, are available for Windows, have a closed architecture, and both offer the possibility to integrate other systems, such as EMG, pressure and force measurement. They have available a library of models, as well as the capability to create or to edit existing models, and the motion data used for the analysis is gathered from an external motion capture system. The human motion simulation is computed in two and three dimensions.

Instance of relevant work that has referred to the surveyed tool: Miles, Pop, Watt, Lawrence, & John, (2012).

Visual3D* (http://www.c-motion.com)

Visual3D, originally named as MOVE3D, was designed for use in the Department of Rehabilitation Medicine at the National Institutes of Health (see (Kepple, 1991)). It is a software tool commercialized by C-Motion, Inc. (USA) and its latest version is 5.01.23 from 2014, available for Windows. This tool provides flexibility for managing, modeling, analyzing, simulating and reporting motion data collected from 2D and 3D systems, giving a real-time biofeedback.

Instance of relevant work that has referred to the surveyed tool: Jones, Kerwin, Irwin, Nokes, & others, (2009).

WINanalyze* (http://www.mikromak.com)

Mikromak GmbH (Germany) developed and commercializes WINanalyze for the tracking and analysis of motion. Its latest version is the 2.6.1 from 2014, and it is Windows-based, with a closed architecture. This tool allows the creation of new models, its edition and it also has available a library of models, that can be used in the two and three-dimensional analysis of the motion, which occurs offline. No simulation is available.

Instances of relevant work that have referred to the surveyed tool: Ahmadi, Shirzad, Sajadi, Cheraghi, & Haghighi, (2010) and Heinen & M. Vinken, (2011).

PROPOSED CLASSIFICATION FRAMEWORK

For the classification framework it was defined a set of features considered as relevant to describe the surveyed software applications. These features were grouped into five main categories: the generic features, the modeling capabilities features, the data acquisition features, and the analysis and simulation features. In the following sections each feature is described briefly.

Generic Features

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

- **Current Version [Release Date]:** Gives a sense of maturity and activity of the application, indicating the tool's latest version and its release date;
- **Academic Project [Seminal Paper]:** Intends to characterize if the tool began as an academic project or not. In case of affirmative, it also indicates the seminal paper (whenever possible);
- **Availability:** Reveals the software availability, i.e., whether if it is a free or a commercial product. In case of a commercial product, it also indicates if a trial version is available;
- **Architecture:** The openness of the software architectures is expressed in this feature, 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.
- **Platforms:** Lists all the available platforms where it is possible to install and run the application.

Modeling Features

It is very important that an analysis/simulation application enables users to create and edit their own models, as well as make available a set of predefined whole-body and/or body-part models. Therefore, the second set of features intends to characterize the modeling capabilities of each tool.

- **Library of Models:** Reveals if the tool has its own collection of models that users can use (*yes/no*).
- **Create New Models:** Indicates the tool's capability to create new models (*yes/no*);
- **Edit Existing Models:** Indicates the tool's possibility to edit existing models (*yes/no*);

Data Acquisition Features

The third category of features refers to data acquisition capabilities, mentioning:

- **Motion Data:** Indicates what type of motion capture system the tool has available (*native*, *external* or *absent*);
- **Analog Data:** Enumerates, if available, all the sources of analogue data that the tool can import (*C3D* - motion data, *EMG* - electromyography, *ECG - electrocardiography*, *force plates*);
- **Data Fusion:** The synchronization of several signals allows a more accurate evaluation of the motion. This feature reveals if the tool enables data fusion (*yes/no*);

Analysis Features

The analysis set of features refers to:

- **Dimensionality:** Indicates the dimensionality that the motion analysis occurs (*2D*, *3D* or *2D/3D*);
- **Real-Time / Offline:** Reveals the timing that the analysis takes place (*real-time*, *offline* or *both*);

Simulation Feature

- **Dimensionality:** Indicates the dimensionality that the motion simulation occurs (*2D*, *3D, 2D/3D* or *doesn't apply*);

Table 1 presents the twenty-five surveyed applications, already classified in respect to the proposed framework. The lines in gray correspond to the tools whose information was retrieved from the questionnaire. The cells with the value "-" means that the feature does not applies for that tool, and the cells with the value "N/A" means that it was not possible to classify the tool in that particular feature.

CONCLUSION AND FUTURE WORK

After examining the table we noticed that more than half of the surveyed tools, 60% of them, were created or reviewed within the last two years, reinforcing the fact that this field of research remains very

Table 1. The surveyed applications classified in respect to the proposed classification framework

	Generic Features					Modeling			Data Acquisition			Analysis		Simulation
Tool	**Current Version**	**Academic Project**	**Availability**	**Architecture**	**Platforms**	**Create New Models**	**Edit Existing Models**	**Library of models**	**Motion Data (Native, External or Absent Mocap System)**	**Analog Data**	**Data Fusion**	**Dimensionality**	**Real-Time / Offline**	**Dimensionality**
Adams	2014 (2014)	No	Commercial	Closed	Windows Linux	Yes	Yes	Yes	External	-	-	3D	Offline	3D
AnimatLab	2.1.2 (2014)	No	Standard (free) Pro (commercial)	Open	Windows Linux	yes	yes	yes	Absent	-	No	3D	Offline	3D
AnyBody Modeling System	6.0.1 (2013)	Yes	Commercial (trial version available)	Closed	Windows	Yes	Yes	Yes	Absent	Motion data EMG Force Plate	Yes	3D	Offline	3D
BTS SMART	N/A (2010)	No	Commercial	Closed	N/A	N/A	N/A	N/A	Native	Motion data EMG Force Plate	Yes	3D	Both	-
Dartfish	v.7 rel. 9 (2014)	No	Commercial (trial version available)	Open	Windows	Yes	Yes	No	Native	Force Plate	No	2D	Offline	-
DMAS	N/A (2005)	No	Commercial	Open	N/A	Yes	Yes	Yes	Native	EMG Force Plate	Yes	3D	Both	-
Hu-M-An	6 (N/A)	Yes	Commercial (trial version available)	Closed	Windows	Yes	Yes	Yes	Native	Force plate	Yes	2D + 3D	Both	2D + 3D
KAPro	7.1 (N/A)	Yes	Free (educational institutions)	Closed	N/A	Yes	Yes	No	Native	-	No	2D + 3D	Offline	-
Kinovea	0.8.23 (2014)	No	Free	Open	Windows	No	No	No	Native	-	No	2D	Offline	-
Kwon3D XP	4.1 (2004)	No	Commercial (trial version available)	Closed	Windows	Yes	Yes	Yes	Native	Motion data Force Plate	Yes	2D + 3D	Offline	-

	Generic Features					Modeling			Data Acquisition			Analysis		Simulation
Tool	**Current Version**	**Academic Project**	**Availability**	**Architecture**	**Platforms**	**Create New Models**	**Edit Existing Models**	**Library of models**	**Motion Data (Native, External or Absent Mocap System)**	**Analog Data**	**Data Fusion**	**Dimensionality**	**Real-Time / Offline**	**Dimensionality**
MaxPRO	1.4.0.1 (2010)	No	Commercial (trial version available)	Open	Windows	No	No	No	Native	Motion data EMG Force Plate	No	3D	Offline	-
MaxTRAQ	2.13 (2009)	No	Commercial (trial version available)	Open	Windows	No	No	No	Native	Motion data EMG Force Plate	Yes	2D + 3D	Offline	-
Mokka	0.6.2 (2013)	Yes	Free	Open	Windows Linux Mac Osx	No	No	No	Absent	Motion data EMG Force Plate	Yes	2D + 3D	Offline	-
Motion Analysis Tools	2.8 (2009)	Yes	Free	Closed	Windows	Yes	No	No	Absent	-	No	2D	Offline	-
MotionGenesis Kane	5.5 (2014)	No	Commercial (trial version available)	Open	Windows Linux Mac Osx	Yes	Yes	Yes	Absent	-	No	2D + 3D	Real-time	2D + 3D
MSMS	2.2 (2012)	Yes	Free	Closed	Windows	Yes	Yes	Yes	External	Motion data EMG	Yes	2D + 3D	Both	3D
MVN Studio BIOMECH	4.0 (2014)	No	Commercial (trial version available)	Closed	Windows Linux	No	Yes	Yes	Native	Own data files	Yes	2D + 3D	Both	3D
ODIN	1.01 (2013)	No	Commercial	Open	windows	No	Yes	Yes	External	Motion data EMG Force Plate	Yes	2D + 3D	Both	-
OpenSim	3.2 (2014)	Yes	Free	Open	Windows	Yes	Yes	Yes	External	Motion data EMG Force Plate	Yes	3D	Both	3D

	Generic Features					Modeling			Data Acquisition			Analysis		Simulation
Tool	Current Version	Academic Project	Availability	Architecture	Platforms	Create New Models	Edit Existing Models	Library of models	Motion Data (Native, External or Absent Mocap System)	Analog Data	Data Fusion	Dimensionality	Real-Time / Offline	Dimensionality
SIMI motion	8.5 (2012)	No	Commercial	Closed	Windows	Yes	Yes	Yes	Native	Motion data EMG Force Plate	Yes	2D + 3D	Offline	-
SIMM	7.0 (2013)	Yes	Commercial	Closed	windows	Yes	Yes	Yes	Native	Motion data EMG Force Plate	-	2D + 3D	Both	3D
Templo	8.0 (2014)	No	Commercial (trial version available)	Closed	windows	No	No	No	Native	EMG Force Plate	Yes	2D	Offline	-
ViconMotus 2D/3D	10 (2014)	No	Commercial	Closed	windows	Yes	Yes	Yes	External	Motion data EMG ECG Force Plate	Yes	2D + 3D	Offline	2D + 3D
Visual3D	5.01.23 (2014)	No	Commercial (trial version available)	Open	Windows	Yes	Yes	Yes	External	Motion data EMG ECG Force Plate	Yes	3D	Both	2D + 3D
WINanalyze	2.6.1 (2014)	No	Commercial	Closed	Windows	Yes	Yes	Yes	Native	EMG ECG Force Plate	-	2D + 3D	Offline	-

active and attractive, with a continuous interest of the scientific community and/or companies. Just a small set of the tools is freely available (20%). Still, 60% of the commercial ones offer a trial version. Eight applications have their origin in projects initiated within the academic community, and currently three of them resulted in business. Most of the tools have a closed architecture, disabling the possibility to expand through new modules or components. Nevertheless, all of them export the computed data during the motion analysis and/or simulation, varying only in formats (text, CSV, and others). Regarding to modeling issues, the majority of the tools have capabilities for creating and editing models, as well as a models repository that can be used for the analysis and/or simulation tasks. Concerning the data acquisition features, fourteen applications have a native motion capture system while five of them use an external one. Still, from the applications that have no motion capture system incorporated, three can import analogue motion data, while the remaining incorporate laws of physics to generate movement. Only six applications do not import any analogue data, while the remaining tools support data from force platforms and/or from electromyography and/or electrocardiography. Finally, eleven tools (44%) can simulate the human motion (either in two or three dimensions), whilst all of them can perform motion analysis: four tools in two dimensions, seven tools in three dimensions and fourteen tools in both dimensions. Sixteen applications perform exclusively an offline motion analysis, while nine can operate either offline as in real-time.

The research work presented in this chapter surveys the state of the art in respect to automated tools in human motion analysis and simulation. We present our perspective on how these tools can be classified and compared and a logical, structured and feature oriented classification framework is described and presented. Key features were 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 and e) simulation - describing the kind of analysis provided and indicating when simulation of human motion models is achievable.

The current evolution of the sensory technology, with the dissemination of low cost vision and biometric sensors, pushes the multiple sensor acquisition and processing as well as data fusion to a high level of relevancy. Other important feature, in our opinion, is the openness, either to allow integration with third party tools, either to provide the experienced practitioner with some extension mechanism that allows development of customized functionality (e.g. scripting language, plugin, SDK). Finally, the ability to instantiate a model with the acquired data to perform simulation is becoming a fundamental requirement in several of the described application domains.

Contributions of this chapter are manifold. First, from the practitioner or researcher perspective, it provides a comprehensive overview of existing tools with instances of example applications and published scientific work making use of them. Moreover, the proposed framework allows the tools to be compared against a set of relevant features aiming at a more informed and efficacious tool selection process. Second, from the developer perspective, the framework is relevant as it provides design options with pointers to their relevancy at established application domains, thus providing an expected aid in the tool design process.

Beyond keeping this study 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 human motion analysis and simulation tools. To fully achieve the aforementioned aim, a user/researcher survey is also envisioned to better define the most prominent features according to their experience.

We expect to integrate these knowledge and experience in order propose a comprehensive taxonomy alongside with detailed relevancy information with respect to the application domain.

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KEY TERMS AND DEFINITIONS

(Computer) Simulation: Is fundamentally an imitation of a real process or system over time. The simulation process encompasses the design of a model of the system and conducting experiments in order to understand its behavior and performance under different conditions (variables).

Computer Vision: Is a discipline that studies methods and algorithms that are able to acquire, process and understand entities represented in images. The ultimate goal is to produce decisions and/or descriptions about the represented entities.

Data Fusion: Refers to a process of combining data, related to a same entity, acquired from multiple sources into an integrated representation, suitable for subsequent unified computational processing and analysis.

EMG: Denoting Electromyography is a technique that is able to record the electrical activity of skeletal muscles. With EMG it is possible to analyze muscle properties such as activity, force, fatigue, etc.

Kinematics: Is the study of motion independently from the forces that produced that motion. It includes the study of geometrical and time based properties of motion such as position, velocity and acceleration.

Kinetics: (Also referred as Dynamics) is the study of motion of bodies having mass and its relationship to its causes such as forces and torques.

Machine Learning: Is a discipline that focuses on the study of algorithms that are able to learn from data and self-improve through experience.

Motion Capture: is a process that captures the motion of animated objects or human beings. Motion is captured via the selection and measuring of particular properties such as well-defined positions (e.g.: joints) and orientations over time. Motion is encoded into a digital representation suitable for simulation, analysis, computer animation, etc.

Musculoskeletal Model: A computational model that encompasses a skeleton consisting in rigid body segments (bones) connected by joints. The skeleton may have several constraints (e.g.: maximum joint angles). Muscles spanning from joints are connected to bones via tendons. Muscles are able to generate forces and movement. These models are very useful on biomechanical analysis and simulation.

Real-Time: Refers to the ability that the system can process input and produce a result within a specified amount of time that should be small enough to be considered timeliness.

RGB-D Camera (Depth Sensor): Are a specific type of depth sensing devices that work in association with a RGB camera, that are able to augment the conventional image with depth information (related with the distance to the sensor) in a per-pixel basis.