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Task-based motion control of digital humans for industrial applications

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Abstract

Nowadays digital substitutes of human beings (digital humans), capable of interacting with digital mock-ups in Virtual Reality, are widely used in many fields of engineering (e.g. ergonomics, product design, maintenance, and training). Nevertheless, the animation process of digital humans is still a time-consuming task, and its accuracy and reliability strongly depend on the experience and the skills of the operator. This paper presents an innovative algorithm capable of significantly speeding up the animation process of digital humans, allowing the operator to focus only on the so-called "task-related control points". This approach allows also to easily conduct biomechanical analyses. The algorithm has been tested with reference to several application scenarios in Virtual Reality.

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Keywords: Virtual reality; Algorithm; Kinematics; Digital humans

1. Introduction

Over the years, manufacturing companies have taken ergonomics and usability as basic parameters of quality for their products. The design approach has been reviewed, giving to the end-users' needs, requests, and limitations an extensive consideration. For this reason, an increasing attention is currently devoted to ergonomics and human factors evaluations even from the early stages of the design process [1-4] (user-centered design approach [5]).

Digital Mock-Ups (DMUs) provided by many computer-aided engineering applications enable manufacturers to design a digital prototype of a product in full details, simulating its functions and predicting interaction among its different components. The production of physical prototypes, which is a very time consuming task, is then deferred to the final stages of the design process [6]. In order to take advantage of digital simulations to conduct ergonomic assessments (computer-aided ergonomics), digital substitutes of human beings capable of interacting with the DMUs in the simulation environment are required. This has given birth to the so-called *digital human modeling* (DHM), which led to the development of many software tools [7,8]. These tools are mainly used to study human–product and human–process interaction and to conduct ergonomic and biomechanical analyses, as well as manual process simulations, even before the physical prototype is available. DMUs, together with digital human models, are increasingly used in order to reduce the development time and cost, as well as to facilitate the prediction of performance and/or safety [9]. The ergonomic design methodology relying on digital human models makes the iterative process of design evaluation, diagnosis and review more rapid and economical [10]. It increases also the quality by minimizing the redundant changes and improves safety of products by eliminating ergonomics related problems.

Furthermore, with the arising of the forth-industrial revolution (Industry 4.0), the concept of the virtualization of the manufacturing processes has gained a greater importance. In this context, human simulation in production activities will certainly play a significant role.

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These digital humans, provided by many process simulation software, are essentially kinematic chains consisting of several segments and joints. As example, Fig. 1a shows the skeleton implemented in Siemens Jack^{TM}. The lengths of their segments, as well as their mass distribution, are derived from anthropometric databases, which can be queried with respect to different percentiles in the population (Fig. 1b).

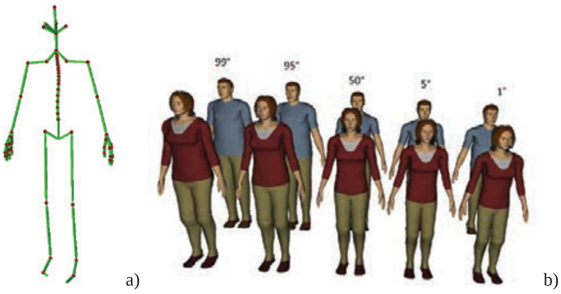

Fig. 1. Skeleton of Jack^{TM} digital human (a); different percentiles of human figures (b).

The "Animation" of these digital humans is still a key-topic. In fact, most of the commercially available software tools are still based on "key-frame" animation techniques. Thus, the animation process of a digital human can be very time consuming, mainly because of the difficulty in achieving a human-like behavior. In fact, although most of the commercially available DHM software already implements effective inverse kinematics (IK) algorithms, they can generally manage only a limited number of links at time. As a result, the accuracy of those simulations is strongly related to the skills and experience of the operator. Full-body motion capture techniques (MoCap) could be a solution, but they are expensive and time-consuming as well. It is clear that a task-oriented approach in simulating human behavior would be more effective than a key-frame technique.

In this paper the HuPOSE algorithm [11] is proposed as an effective tool for the animation of digital humans. The algorithm has been tested with reference to a possible computer-assisted training session for a human worker. A load-lifting task has been simulated to train an operator to fulfill the assigned task, taking a correct posture. In [11] HuPOSE algorithm was used in order to animate Jack^{TM}. In this work, the computer-assisted training session has been implemented in Blender and bvhacker, relying on BVH data format, in order to show that HuPOSE is a general-purpose algorithm, which is suitable for the animation of a wide range of digital human models.

2. HuPOSE Modeling

HuPOSE algorithm aims at generating human-like postures for a highly redundant kinematic chain, such as a human figure, by means of a limited number of task-related control points, without the need of specifying each joint variable of the kinematic chain. Moreover, given the formulation of the algorithm in terms of a single Augmented Jacobian matrix, also biomechanical analyses are easy to implement [12]. These goals have been achieved using the typical serial robots modeling techniques [13].

2.1. Kinematic Modeling

With reference to a serial manipulator, and its Forward Kinematics (FK) equations, changing the value of its Denavit-Hartenberg (DH) parameters results in the kinematic equations of another manipulator, whose end effector is located before the real one, that is equivalent to moving the control point of the kinematic structure. If the DH values are described in a symbolic form, they are such to identify an arbitrary point as a Virtual End Effector (VEE) [14] of a smaller manipulator considered for the control.

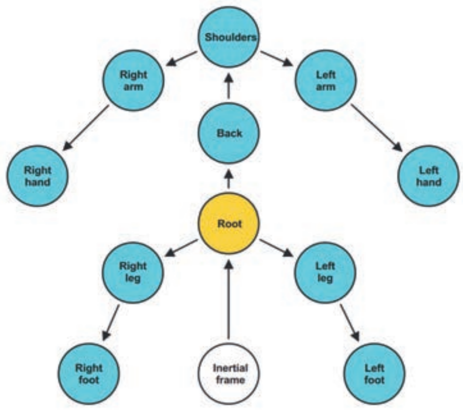

Fig. 2. Hierarchical structure of the humanoid

Thus, an arbitrary number of such control points can be considered. In order to take advantage of the systematic approach typically used for serial robots, the human figure was modeled as the combination of four kinematic chains, which share the same starting point, located at the hip and called *root*. The resulting hierarchical structure is shown in Fig. 2. One or more control points can be selected on the kinematic structure, through the proper set of DH parameters that specify such points.

Unlike serial robots, a human figure is bound to the ground by a one-way constraint, which is the current support plane, for instance one foot.

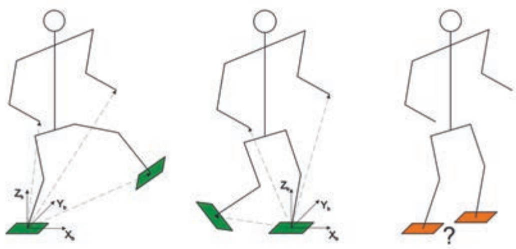

Fig. 3. Problem of identifying the reference frame