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Dynamic control of DHM for ergonomic assessments

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A B S T R A C T

Physical risk factors assessment is usually conducted by analysing postures and forces implemented by the operator during a work-task performance. A basic analysis can rely on questionnaires and video analysis, but more accurate comprehensive analysis generally requires complex expensive instrumentation, which may hamper movement task performance.

In recent years, it has become possible to study the ergonomic aspects of a workstation from the initial design process, by using digital human model (DHM) software packages such as Pro/ENGINEER Manikin, JACK, RAMSIS or CATIA-DELMIA Human. However, a number of limitations concerning the use of DHM have been identified, for example biomechanical approximations, static calculation, description of the probable future situation or statistical data on human performance characteristics. Furthermore, the most common DHM used in the design process are controlled through inverse kinematic techniques, which may not be suitable for all situations to be simulated.

A dynamic DHM automatically controlled in force and acceleration would therefore be an important contribution to analysing ergonomic aspects, especially when it comes to movement, applied forces and joint torques evaluation. Such a DHM would fill the gap between measurements made on the operator performing the task and simulations made using a static DHM.

In this paper, we introduce the principles of a new autonomous dynamic DHM, then describe an application and validation case based on an industrial assembly task adapted and implemented in the laboratory. An ergonomic assessment of both the real task and the simulation was conducted based on analysing the operator/manikin's joint angles and applied force in accordance with machinery safety standards (Standard NF EN ISO 1005-1 to 5 and OCcupational Repetitive Actions (OCRA) index). Given minimum description parameters of the task and subject, our DHM provides a simulation whose ergonomic assessment agrees with experimental evaluation.

Relevance to Industry: A new autonomous dynamic DHM was developed to study the ergonomic aspects of a workstation. When designing a new work-task, our DHM requires minimal information for a simulation and changing the subject's anthropometry and the scenario does not require new trajectory specification nor additional tuning.

1. Introduction

Work-related musculoskeletal disorders (WRMSD) represent a major proportion of registered and/or compensatable work-related diseases in many countries (Sjogaard et al., 1995; Bernard, 1997), particularly those involving the lower back, neck, shoulder, forearm and wrist.

Several studies have identified a relationship between "work-related" diseases and physical risk factors at work (Bernard, 1997; Kao, 2003). Job physical characteristics frequently quoted as WRMSD risk factors, based on experimental science and epidemiologic investigations, include rapid and repetitive motion patterns, heavy lifting, forceful manual exertions or prolonged static postures. As a result, safety standards have gradually detailed those issues and physical risk factor assessment at the earliest design stages has become a concern for industrial companies.

A basic analysis of a task can rely on questionnaires, interviews and video analysis. Besides, numerous indicators can be used for physical risk assessment of job activities, usually specific to a body

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part or a type of activity: commonly encountered assessment methodologies include RULA (MacAtamney and Cortlett, 1993) for the upper limbs, REBA (Hignett and MacAtamney, 2000) for the whole body, NIOSH equations, standards such as NF EN 1005 – Part2 (AFNOR, 2003) for load handling or NF EN 1005 – Part 5 (AFNOR, 2007) for repetitive tasks (this standard is based on the OCcupational Repetitive Action (OCRA) method (Occhipinti, 1998)). A more accurate and comprehensive analysis requires collection of exertion (force sensor and/or electromyography) and posture data (e.g. motion capture technique) from operators performing similar tasks. This analysis entails complex expensive instrumentation that may hamper task performance.

When designing a new task, an alternative is to use digital human models (DHM) for ergonomic analysis. For example, Subsection 4.2.5 of EN 1005-4 states that DHM can be used for anthropometry and postures assessment (AFNOR, 2008). Using DHM, it is currently possible to study, analyse and visualize complex movements or postures in a user-friendly three-dimensional graphical interface. Hence, an initial level of future workstation ergonomic assessment is possible even at the early stages of the design process without the need for direct measurements on human subjects (Chaffin, 2005; Gomes et al., 1999; Dukic et al., 2007). Examples of DHM software packages used for ergonomic assessment are Pro/ENGINEER Manikin Analysis, SAMMIE (Porter et al., 2004), JACK (Badler, 1997), CATIA-HUMAN Design and Analysis tools, RAMSIS and SANTOS.

However the simulations computed with these software packages usually rely on kinematics animation frameworks. Such frameworks use either pre-recorded motions, obtained through tracking system and motion capture, or interactive manual positioning of the DHM body through mouse, menus and keyboard. In the first case, simulations are realistic but they require extensive instrumentation of a full scale mock-up of the future workstation or a similar existing one. They are extremely time consuming because of motion capture data processing (Bradwell and Li, 2008). Furthermore, their ability to predict complex human postures and movements for various sizes and dimensions in a timely and realistic manner is strictly dependent on the accuracy of the motion database. In the second case, simulations are fairly subjective (the designer, possibly with no specific ergonomic skill, chooses arbitrarily a posture or trajectory). Again, they are time consuming (built up like a cartoon) or usually appear unnatural (Chaffin, 2007), even though they possess semi-automatic controls provided by a set of behaviours such as gazing, reaching, walking and grasping. These issues do not encourage designers to consider alternative scenarios, which would be beneficial for a comprehensive assessment of the future work situation. Moreover, such software packages are subject to numerous limitations: restriction to static models and calculation, neglect of balance or posture maintaining exertion. Neither do they consider contact forces between the DHM and objects (at best the designer has to arbitrarily set the contact force magnitude and direction manually). For these reasons, assessment of biomechanical risk factors, based on simulations of industrial or experimental situations, may lead to real stress underestimation up to 40–50% (Lamkull et al., 2009; Savin, 2011).

A challenging aim therefore consists in developing a virtual human model capable of computing automatic, dynamic, realistic movements and internal characteristics (position, velocities, accelerations and torques) in quasi-real time, based on a simple description of the future work task, to achieve realistic ergonomics assessments of various work task scenarii at an early stage of the design process.

This type of dynamic DHM controlled in acceleration and force using simulated physics, forms the crux of our research. In our simulation framework, the entire motion of the human model in the virtual environment is dictated by real-world Newtonian physical and mechanical simulation, along with automatic control of applied forces and torques. We focus on repetitive tasks of the upper limb in this paper, which introduces our virtual human model and demonstrates its possibilities for physical risk evaluation at the design stage. The first and the second parts of the paper describe the application case used as an experimental and validation frame, then outline the principles of our dynamic DHM controls. The third part describes its outcomes, especially comparison of assessments based on real and simulated data. Finally, in the fourth part, we discuss the issues raised by the approach and its prospects.

2. Human subject experiment

2.1. Experimental task description

The research frame focuses on repetitive activities that present a significant risk of upper limb WRMSD. Our case study deals with the task of insert fitting. This activity comes from the automotive industry but can also be found in electric household appliance or other industries, in which the constant product evolution results in frequent, quick changes to production lines, requiring multiple manual operations. Insert fitting here consists in clipping small metal parts to the plastic instrument panel of a vehicle prior to screwing components to the panel.

2.2. Subjects

Our application case was first studied during an ergonomic assistance assignment conducted by France's Institut national de recherche et de sécurité (INRS), Laboratory for Biomechanics and Ergonomics (Gaudez, 2008). The same team subsequently adapted it to laboratory experimentation in accordance with biomedical research requirements. Eleven healthy right-handed subjects (nine males and two females) took part in the study [age = 29.4 ± 9.2 yrs (mean ± standard deviation), height = 177.7 ± 10.3 cm, body mass = 75.9 ± 9.3 kg]. The subjects gave their informed consent to the experiments, which were approved by the institutional ethics committee, and completed a health questionnaire. The subject's anthropometry was measured to build human subject models based on the Hanavan model (Hanavan, 1964) (size, weight and 41 body segment measurements).

2.3. Apparatus

The workstation (Fig. 1) comprised a force platform assembled on a lift table fitted with a row of ten insert supports arranged at 45°, from back to front in the sagittal plane.

A ten camera Motion Analysis System was implemented to record the whole body positions and postures. A single top view camera, synchronized with the motion capture system, was used to record the subject's activity: these recordings could subsequently be used to view the real movements and correct for marker losses or hidden movements.

The external force exerted during the activity was measured by the force platform attached to the table (AMTI, model BP600900-1000). This recorded both forces and moments in three spatial planes.

Data were recorded from the Motion Analysis System and the force platform simultaneously at a 100 Hz sampling rate.

2.4. Experimental procedure

Subjects were asked to perform the experimental task according to the two methods used in the workshop: either using only fingers