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A lightweight approach for human factor assessment in virtual assembly designs: an evaluation model for postural risk and metabolic workload

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Abstract

The assessment and optimisation of postural stress and physical fatigue can be challenging and is typically conducted only after the design of manual operations has been finalised. However early assessment of manual operations and identification of critical factors that are deemed outside of an appropriate envelope can avoid the time and costs often associated with re-designing machines and layout for operator work processes. This research presents a low cost software solution based on a simplified skeleton model that uses operator position and workload data extracted from a simulation model used for virtual manufacturing process planning. The developed approach aims to assess postural stress and physical fatigue scores of assembly operations, as they are being designed and simulated virtually. The model is based on the Automotive Assembly Worksheet and the Garg's metabolic rate prediction model. The proposed research focuses on the integration of virtual process planning, ergonomic and metabolic analysis tools, and on automating human factor assessment to enable optimisation of assembly operations and workload capabilities at early design stage.

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Keywords: Assembly ergonomics; Postural stress; Physical fatigue; Virtual human model.

1. Introduction

In manual and semi-automatic workstations, the role of human operators is crucial as it directly impacts the operation cycle time, quality and feasibility as well as operational safety and health [1]. Due to the increase in average employee age, the probability of the occurrence of musculoskeletal disorders (MSDs), especially among workers who perform physically demanding tasks has increased [2]. As a result, legislation has been passed in many industrial countries to ensure manufacturers maintain worker health and prevent work-related safety issues [3]. Recent studies have revealed that processes and workplaces designed according to ergonomic principles both improve occupational health and enhance productivity [4]. It is important to evaluate process ergonomics at the early design stage as the re-design during try-out phase can incur significant costs and the loss of production [5]. Thus there is a need to develop tools and methods that evaluate human factors at the planning phase. Nowadays, digital human models (DHM) integrated computer aided tools (CATs) are considered a promising proactive approach to the evaluation of ergonomics. In general, DHM integrated CATs use three dimensional anthropometric manikin representations and simulations to evaluate the safety and performance of manufacturing operations, and can contribute to reducing overall design and engineering costs [6]. They allow rapid virtual prototype development without putting the operator at risk and negate the need for physical mock-ups and production trials [5]. Also, intuitive 3D representation provided by the DHM tools can improve cooperation between designers, engineers and operators by providing a common understanding of design alternatives [7].

In the last decade, a large variety of academic projects have been conducted using DHM for proactive evaluation of ergonomics issues and many commercial tools have also been introduced to the global market (e.g. Dassault Systèmes' SAFEWORK, Siemens/Technomatix's JACK, RAMSIS, MAthematical DYnamic MOdels (MADYMO), 3D Static Strength Prediction Program (3DSSPP) and SANTOS). Common methods integrated into the DHM tools include;

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Rapid Upper Limb Assessment (RULA) [8], the National Institute for Occupational Safety and Health (NIOSH) [9], European Assembly Worksheet (EAWS) [10], Job Strain Index (JSI) [11] and Rapid Entire Body Assessment (REBA) [12]. Despite the potential benefit of DHM, several limitations may impede their effective deployment and use in a real production environment:

- Most tools only allow the analysis of static scenes using ergonomic assessment methods that are developed for a particular risk factor group [5]. For example, RULA focuses only on body postures whereas the NIOSH is used for the manual material handling.
- Identification and interpretation of ergonomic issues require expert skills, which means that designers with insufficient knowledge regarding the specific methods and their limitations, may conclude to inaccurate results [13].
- According to Backstrand et al. [14], a language gap between method used by DHM tool and the company-specific ergonomic knowledge exists. An integration between DMH tool and company specific CAE software environment is therefore required.
- Most tools currently used in the industry are relatively expensive for small and medium enterprises (SMEs). Therefore, development of the low cost and lightweight solutions to enable SMEs to assess human factors is highly valuable.

To address these limitations, a DHM based human factor assessment approach offers a stand-alone, lightweight and quickly deployable design analysis for supporting of operator work sequences is designed and developed in the current article. The developed model uses simplified virtual manikin skeleton and has the ability to rapidly evaluate both working postures and physical work fatigue using intuitive and non-specialist software function and GUI. This has a significant impact on the time and skill required to edit a virtual model/simulation of a manual operation, hence allowing to contribute to the 100% virtual modelling and validation target.

2. Module descriptions

2.1. The vueOne VM tool and V-Man module

The research conducted by the Automation Systems Group (ASG) at the University of Warwick is focusing on the design and implementation of automation systems tools and methods that contribute in supporting both throughput and life cycle of automation systems. As a part of research, the ASG developed an engineering environment, called vueOne for assembly sequence planning and validation. The vueOne tool is currently being used to support virtual engineering activities at several companies operating in the sectors of automotive powertrain and battery production. The vueOne offers a set of software modules that target key engineering domains of automated production systems design. The work presented in this paper relates to the *V-Man* (Virtual Manikin) module of the vueOne toolset (Figure 1).

Manual operations in vueOne are modelled using the *V-Man* module (Fig 2) which provides a set of functions and a user interface to design, simulate and validate human operator work sequences. The *V-Man* module offers intuitive posture and move sequence editing capabilities and includes different sizes of anthropometric digital manikins (5th, 50th and 95th percentile for male and female). Currently, the *V-Man* is using a 13 independent joints skeleton with 3D interactive jog controls and is able to perform predetermined motions as defined by the MODAPTS (see [15]), such as; crouch, kneeling, torso rotation, foot rotation and move. In vueOne, a *V-Man* operation is described as a finite state machine (FSM), which outlines the production process that the *V-Man* will follow. A *V-Man* FSM consists of static and dynamic states. In each dynamic state, the V-Man completes the corresponding pre-determined sequence of moves. The *V-Man* timeline displays all the virtual manikin movements. Each row within the timeline corresponds to a part of the body such as feet position/rotation, left/right hand and left/right hand actions, and carries specific information such as walking distance and working arm distance. These data can be exported to an XML formatted file that can be used as input to additional engineering processes such as discrete event simulation and energy analysis. In this research, postural stress and fatigue assessment modules have been introduced that are fed by this data. To integrate these modules with vueOne, a set of data recording, processing and reporting mechanisms are also described.

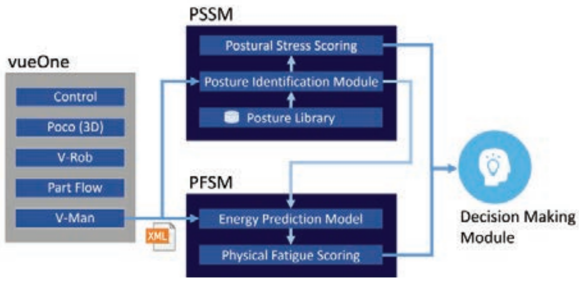

Fig. 1. Interaction between proposed modules and vueOne virtual manufacturing tool.

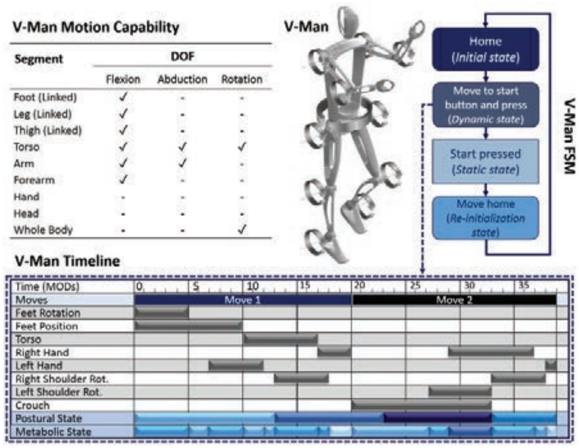

Fig. 2. Virtual manikin module; V-Man motion capability, V-Man FSM and V-Man operation sequence timeline.