Computers & Industrial Engineering 77 (2014) 1–10

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Innovative real-time system to integrate ergonomic evaluations into warehouse design and management

Daria Battini, Alessandro Persona, Fabio Sgarbossa *

Department of Management and Engineering, University of Padova, Stradella San Nicola, 3, 36100 Vicenza , Italy

ARTICLE INFO

Article history:
Received 11 January 2014
Received in revised form 25 June 2014
Accepted 26 August 2014
Available online 6 September 2014

Keywords:
Real-time ergonomics evaluation
Motion capture system
Warehousing operations
Industrial applications

ABSTRACT

The present paper introduces an innovative full-body system for the real-time ergonomics evaluations of manual material handling in warehouse environments, where all parts of the body are interested during the activities execution. The system is based on inertial sensors with integrated compensation of magnetic interference and long wireless connection that permit its use also in heavy industrial applications. A specific set of tools has been developed in order to elaborate the collected motion data and give real-time evaluation and feedback of ergonomics based on the most used methodologies and extended with others advanced ad hoc tools, such as hands positions analysis, travel distance, time and methods collection calculations. The system has been applied to two different warehouses both for the re-design of the storage area and successively management of the typical warehousing activities, such as picking, packing and others, reducing the risk of musculoskeletal disorders and simultaneous increasing of productivity of systems.

1. Introduction

In the modern global supply chain context, more and more attention has been paid to the warehousing aspects for multiple reasons. Even if stocking facilities are extremely necessary to solve the traditional supply chain imbalances, they are seen as cost centers, both for blocked investment capitals and for high-human resources consume.

Moreover, global competition and markets extreme variability have led societies to order, purchase, produce and sell smaller and smaller quantities of products, doing this very often.

Furthermore, the optimization of productive and assembly systems also involved a distinct separation between the production/assembly activities and the preparation of components and semi-finished products supplying these systems.

All this pushed societies and the academic world to pay more attention to the design and management of warehouses, both for finished and work in process products.

In these stocking systems, picking activities are very important as highlighted in literature (Coley et al., 1996; Grosse, Glock, & Jaber 2013) because of an important expenditure of human resources, between 50% and 75%.

In the last years, due to the high incidence of manual activities in the warehousing operations, such as lifting, picking, sorting, pushing, pulling and others, the well-being of the operators has been widely studied. van Reenen et al. (2008) have argued that the future long-term muscular pain, such as musculoskeletal disorders (MSDs), depends on the discomfort felt by the warehouse operators. Generally, MSDs caused by manual tasks represent a large part of all work-related MSDs (Burgess-Limerick, 2007; Euzenat, 2010) and are a central issue for public health (Martinelli, 2010).

As well demonstrated in Battini, Faccio, Persona, and Sgarbossa (2011), it is important to include also the ergonomics evaluations in the human operations analysis due to the strictly interaction between productivity and motion efficiency and operational safety.

A lot of methods and tools have been developed to help the engineering and managers estimate the incorrect postures and related activities for several industrial contexts.

The particular aspects of the warehousing activities which involve all body parts and the wide differences between each of them require the use of more than one ergonomics evaluation method in order to have a global accurate assessment.

Several of these ergonomics evaluation methods includes OCRA, NIOSH lifting equation, RULA, REBA, HAL-TLV, OWAS, LUBA, OCRA, Strain index, SNOOK tables (Andreoni et al., 2009).

Each of them has different features and considers different aspects useful for ergonomics evaluations, as explained in Fig. 1 and Table 1.

* Corresponding author.
E-mail addresses: daria.battini@unipd.it (D. Battini), alessandro.persona@unipd.it (A. Persona), fabio.sgarbossa@unipd.it (F. Sgarbossa).

http://dx.doi.org/10.1016/j.cie.2014.08.018
0360-8352/

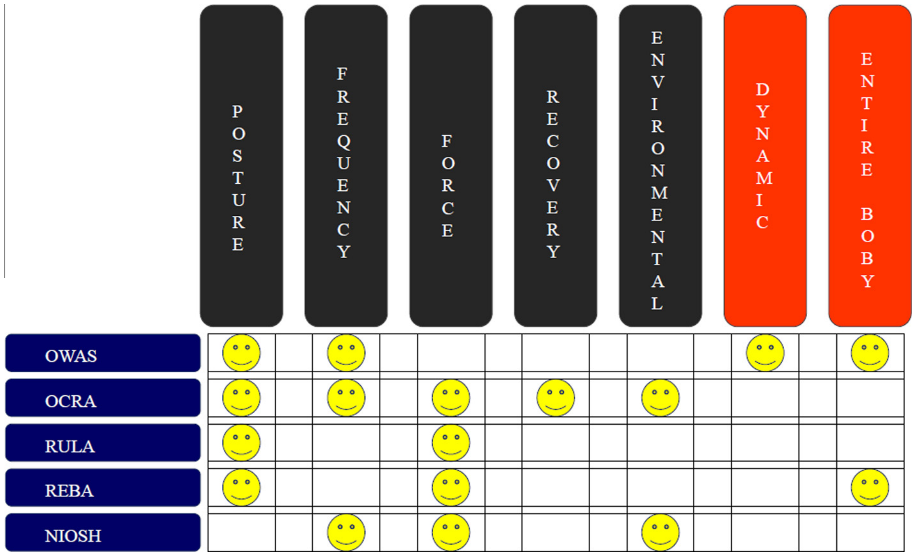

Fig. 1. Main ergonomics evaluation methods and their characteristics.

Table 1
Classification of the most used ergonomics methods.

Method	When	Focus	References
BORG SCALE	Perceived exertion evaluation	Simple method to measure physical activity intensity levels	Borg (1970)
OWAS Ovako Working Analysis System	Fast postural targeting	Work-related disorders on 4 basic body portion without detail on upper limb, verifying the frequency and the time taken in each posture.	Karhu et al. (1977)
RULA Rapid Upper Limb Assessment		Fast evaluation of upper body members constraints	McAtamney and Corlett (1993)
REBA Rapid Entire Body Assessment		Fast evaluation of the whole body and highlight the fast change of postures	Hignett and y McAtamney (2000)
Strain index	Repetitive movements evaluation	Upper limb repetitive movement equation	Moore and y Garg (1995)
OCRA Occupational Repetitive Action		Upper limb repetitive movements evaluation check list	Colombini et al. (2002)
Snook and Ciriello	Manual lifting evaluation	Evaluation tables of maximum acceptable weights and forces".	Ciriello and Snook (1978)
NIOSH National Institute of Occupational Safety and Health		Lifting equation that define the RWL: Recommended Weight Limit	Niosh (1981)

Moreover the ergonomics assessment methods can be applied using different tools, which can be divided into self-report, observational tools, virtual simulations and direct measurements with different limitations, advantages and applications (David, 2005; Honglun, Shouqian, & Yunhe, 2007; Li & Buckle, 1999).

Self-reports involve worker diaries, interviews and questionnaires. Having a relevant subjective aspect due to the different possible interpretation, comprehension and perception of fatigue by the operators, their uses are limited and the results need to be understood and validated.

The observational tools introduce some predefined sheets to be used during the direct observation or using the video-records. Typically, these are composed by several tables where the evaluators remark the operators' postures during the execution of the analyzed tasks. The detail of the analysis, as part of the body under evaluation, depends on the methodology used for the ergonomics assessment. The results are typically defined as evaluation indices which are compared successfully to threshold values. These kinds of tools are widely used in very different situations, but they are very time consuming and the scoring system is questionable, too.

The virtual simulations tools are typically 3D-CAD software where human models are constructed and their activities are simulated. Several of these include some ergonomics evaluation methods as internal tools. In this case, high experience in the 3D modeling is necessary in order to make the model in reasonable time. Moreover only few methodologies are implemented in these software. Consequently, these aspects limit the use of these tools just in very few cases.

Finally, in the last years, direct measurement tools are developed introducing real-time posture data collection using sensors placed on the operators under analysis (Bernmark & Wiktorin, 2002; Freivalds, Kong, You, & Park, 2000; Radwin & Lin, 1993). As discussed by David (2005) these methods require a complex and cost-intensive hardware setup and a lot of effort to analyze and interpret recorded data in real-time. As a consequence, the ergonomic evaluation of the directly assessed behavior has to be performed offline.

On the other hand, Mullineaux, Underwood, Shapiro, and Hall (2012) and Vignais et al. (2013) have demonstrated that real-time postural evaluation with simultaneous feedback to the operator provides benefits in practice.

However, these tools present several important limitations: first of all they are applied only in a well-controlled environment, such as a laboratory; then they are limited to the upper body and RULA methodology is the only one applied with all its limitations defined in previous researches, such as some angle thresholds, upper arm abduction or neck twist.