Innovative system for real-time ergonomic feedback in industrial manufacturing

Nicolas Vignais [a],[*], Markus Miezal [b], Gabriele Bleser [b], Katharina Mura [c], Dominic Gorecky [c], Frédéric Marin [a]

[a] UMR CNRS 7338 Biomechanics and Bioengineering, University of Technology of Compiègne, Research Center, Dct Schweitzer Street, 60200 Compiègne, France
[b] DFKI GmbH, German Research Center for Artificial Intelligence, Trippstadter Strasse 122, D-67663 Kaiserslautern, Germany
[c] SmartFactory[KL], Trippstadter Strasse 122, 67663 Kaiserslautern, Germany

ARTICLE INFO

ABSTRACT

This work presents a system that permits a real-time ergonomic assessment of manual tasks in an industrial environment. First, a biomechanical model of the upper body has been developed by using inertial sensors placed at different locations on the upper body. Based on this model, a computerized RULA ergonomic assessment was implemented to permit a global risk assessment of musculoskeletal disorders in real-time. Furthermore, local scores were calculated per segment, e.g. the neck region, and gave information on the local risks for musculoskeletal disorders. Visual information was fed back to the user by using a see-through head mounted display. Additional visual highlighting and auditory warnings were provided when some predefined thresholds were exceeded. In a user study ($N = 12$ participants) a group with the RULA feedback was compared to a control group. Results demonstrate that the real-time ergonomic feedback significantly decreased the outcome of both globally as well as locally hazardous RULA values that are associated with increased risk for musculoskeletal disorders. Task execution time did not differ between groups. The real-time ergonomic tool introduced in this study has the potential to considerably reduce the risk of musculoskeletal disorders in industrial settings. Implications for ergonomics in manufacturing and user feedback modalities are further discussed.

1. Introduction

The human worker plays an important role as operator and troubleshooter in modern and complex manufacturing systems. Many aspects of industrial work are of a physical nature, especially manual tasks, e.g. when the human worker has to pick up a component or arrange it in the assembly position. More generally, any kind of physical activity, such as lifting, pushing, pulling, carrying, moving, manipulating, holding or restraining objects, is considered to be a manual task (COSH, 2010). However, musculoskeletal disorders (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. Ergonomics specialists may identify conditions under which the risk of work-related MSDs is high and develop adequate interventions (Waters, 2012). Moreover, these specialists play an increasing role in industry since they can also influence motion efficiency, operational safety and productivity (Battini et al., 2011; Thun et al., 2011).

Thus, developing supportive tools for the identification and evaluation of potentially hazardous motor tasks and postures is crucial for ergonomics researchers.

Different methods and tools exist for the ergonomic assessment of manual tasks. A non-exhaustive list of them includes QEC, manTRA, RULA, REBA, HAL-TLV, OWAS, LUBA, OCRA, Strain Index, SNOOK tables and the NIOSH lifting equation (Andreoni et al., 2009). They can be classified into self-reports, observational methods and direct measurements (Li and Buckle, 1999; David, 2005). Firstly, self-reports involve worker diaries, interviews and questionnaires. This method has been used for the ergonomic assessment of handling work by Balogh et al. (2001) which constructed valid indices for mechanical exposure of the shoulder–neck region. Nevertheless, self-reports entail some drawbacks like the unreliability of exposure perception and comprehension or interpretation according to the worker's literacy. Secondly, observational methods aim to assess workplace exposure by evaluating the worker's behavior on pro-forma sheets either while observing in the field or replaying videos. The Rapid Upper Limb Assessment (RULA) index is one of the most cited. This tool is based on the observation of the postures during a certain task and outputs biomechanical and postural load values on the whole body with

* Corresponding author. Tel.: +33 3 44 23 43 89; fax: +3 33 44 23 79 42.
E-mail address: nicolas.vignais@utc.fr (N. Vignais).

particular attention to the neck, trunk and upper limbs (McAtamney and Corlett, 1993). Observational methods based on videotaped work sequences analyze different kinds of manual tasks with specific software (Yen and Radwin, 1995; Chang et al., 2010; Radwin, 2011). Observational methods are affordable and practical for use in a wide range of professional situations (David, 2005). However, the scoring system may be questionable according to limited original epidemiological data. Video-based observational methods are also time consuming. Direct methods, in contrast, measure the risk of exposure in real-time by using sensors directly attached to the worker's body. Some of these methods have been employed to study upper limbs (Radwin and Lin, 1993; Freivalds et al., 2000; Bernmark and Wiktorin, 2002). Nevertheless, all these methods require a complex and cost-intensive hardware setup and a lot of effort to analyze and interpret recorded data in real-time (David, 2005). As a consequence, the ergonomic evaluation of the directly assessed behavior has to be performed offline.

Yet, postural evaluation that can be carried out in real-time provides benefits in practice (Mullineaux et al., 2012). If the system provides the worker with information concerning his current ergonomic behavior, then postures could be modified immediately. Furthermore, in the long run, associations between certain postures and their hazardousness could be learned. In order to receive the immediate feedback, Augmented Reality (AR) technology can be used during the actual work execution (Udani et al., 2012). Recent developments in sensor technology offer potential for regular industrial use in contrast to other tracking devices, such as range cameras or magnetic sensors, that are more effective in virtual environments (Ray and Teizer, 2012; Jayaram et al., 2006). For instance, an inertial measurement unit (IMUs) is a small-sized, inexpensive and low-power device suitable for monitoring the kinematics of a segment in real-time (Breen et al., 2009). If several inertial measurement units are connected, biomechanical models can be developed to capture a wide range of movements (Roetenberg et al., 2009).

The aim of this study is to introduce an innovative and practical system for ergonomic assessment of a worker's activity in real-time. The worker's movements are recorded by using a light-weight sensor network composed of synchronized inertial measurements units (IMUs) and goniometers linked to an upper body biomechanical model. In order to perform the ergonomic evaluation in real-time, the RULA index is continuously computed from this biomechanical model. The RULA assessment is simultaneously fed back to the user via a see-through head-mounted display (STHMD). A user study was conducted in order to reveal the influence of the proposed ergonomic feedback on workers' motions during manual task execution.

2. Materials and methods

In the first part of this paper, the data collection process based on the on-body sensor network and the biomechanical model of the upper body are introduced. Then, the real-time ergonomic computation based on the RULA sheet is described. Finally, a user study aiming at the evaluation of the real-time ergonomic feedback is presented.

2.1. Data collection

2.1.1. On-body sensor network

The RULA score computation requires information about joint angles and segment orientations. These two parameters were derived using an on-body sensor network and a mobile processing unit (in this case, a standard laptop). This system is composed of seven wireless *Colibri* IMUs (*Trivisio GmbH*, Trier, Germany). Each lightweight sensor (48 g, 56 × 42 × 19 mm) contains a tri-axial accelerometer, a tri-axial gyroscope and a tri-axial magneto-inductive magnetic sensor. All sensors are sampled at 100 Hz. The IMUs are placed on the worker's body as follows: one IMU for each upper arm, one IMU for each forearm, one IMU for the head, placed on the STHMD, one IMU for the trunk, located on the chest, and one IMU for the pelvis, placed on the sacrum (see Fig. 1a). This last IMU is necessary to define the movement of the trunk with respect to the pelvis segment. In order to record wrist angles (flexion/extension, radial/ulnar deviation), bi-axial SG65 goniometers (*Biometrics Ltd.*, Newport, UK) have been added to the on-body sensor network and synchronized with the IMUs.

2.1.2. Biomechanical model of the upper body

The worker's upper body is then represented by a biomechanical model composed of ten rigid segments (trunk, clavicles, upper arms, forearms, hands and head) connected by anatomically motivated restricted articulations (pelvis, neck joint, sternoclavicular joints, shoulders, elbows and wrists) (see Fig. 1b). This
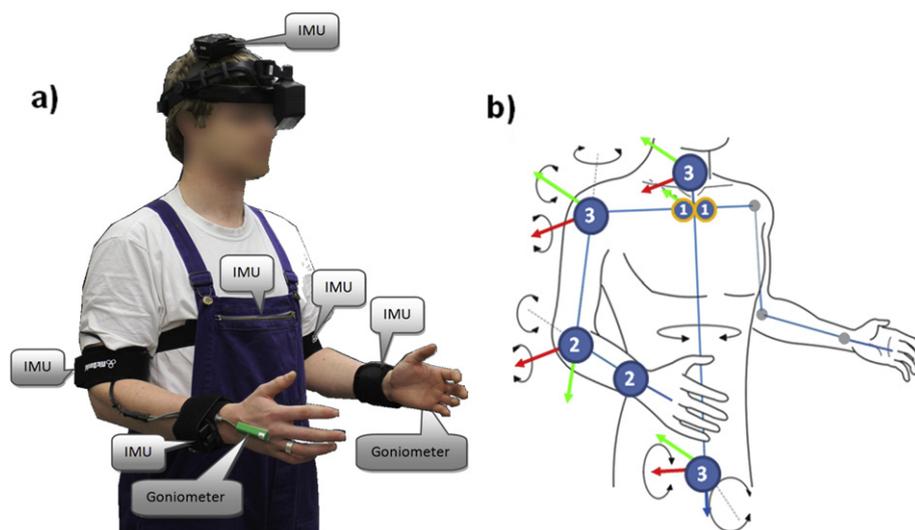
Fig. 1. On-body sensor network composed of IMUs coupled with goniometers (a) and underlying biomechanical model of the upper body (b) with rotation axes for local body frames, and DoF of each joint.