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Incorporating motion analysis technology into modular arrangement of predetermined time standard (MODAPTS)

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ABSTRACT

Implementing new strategies to achieve higher work efficiency is essential to improve productivity during a monotonous and exhausting work task. The Modular Arrangement of Predetermined Time Standard (MODAPTS) concept is widely used to achieve these goals in the field of human factors. However, MODAPTS is very complicated with regard to assisting engineers in understanding the system because it requires much learning time and even longer hours of effort during coding manual process. To help overcome the deficiency of the traditional method, a modern method for motion analysis, called PCA-based motion analysis, is proposed in this paper. Motion analysis has already been the main approach to analyze human motion in sports science and biometrics, but it is still unfamiliar for human factors analysts. This paper discusses a potential connection between motion analysis technology and MODAPTS analysis, which would help make MODAPTS more efficient and reliable. In the experiment, fifteen participants were asked to watch a motion sequence and then analyze the motion sequence using MODAPTS. Meanwhile, the motion-captured data were carefully segmented into motion elements with the PCA approach. A comparison of the motion segmentation contrast was made between MODAPTS analysis and automatic motion element segmentation using PCA. The accuracy rate of segmentation by the PCA approach was 80.08%, and the primitive frames of the two methods indicated that the segmentation is acceptable. In addition, the PCA-based motion analysis showed a substantial time-saving difference in the processing time, which was only approximately 3 min for motion analysis versus over 1 h for MODAPTS. Motion analysis provides high efficiency and reliability for motion segmentation and sufficient precision compared to the results using MODAPTS. Moreover, assessment of the operations' rationality and optimization of the production line design instead of repetitive work on motion segmentation is the focus. Integrating motion analysis technology into traditional MODAPTS is a useful advancement that permits significant progress for human factors analysis. In the future, the accuracy of the automatic segmentation techniques should be improved.

Relevance to industry: In recent years, motion analysis technology has become increasingly popular in various fields but not in the field of human factors. The automatic method presented in this paper may allow industrial workers to optimize unreasonable motion, remove unnecessary operations and formulate the standard working time more conveniently and accurately.

1. Introduction

The widespread necessity of time control and efficiency improvement has motivated new developments in industry. Predetermined Motion Time Systems (PMTS) have gained considerable importance in the fields of home appliances and cars (Razmi and Shakhs-Niyaee, 2008). Historically, PMTS have been the most

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common technique to determine work measurement and production standards (Genaidy et al., 1989; Ma et al., 2010; Wells et al., 2007). PMTS can determine the appropriate assembly time, regardless of whether the station is existent (Razmi and Shakhs-Niyaee, 2008). The concept of PMTS is widely accepted as an integration of information, procedures, techniques and motion times, which is used in the evaluation of manual work elements (Kishino and Hayashi, 1995). The application of PMTS can help to evaluate equipment, improve existing methods, balance production lines and establish standard time (Hoffmann et al., 1993; Beek et al., 2013). In essence, PMTS is based on two fundamental assumptions: (1) a precise general time value can be assigned to each basic motion, and (2) the accumulation of individual basic motion values is equal to the whole task time value (Genaidy et al., 1989). Modular Arrangement of Predetermined Time Standard (MODAPTS) is one of the many PMTS methods that are useful for explicitly evaluating differences in operating time (Kanai et al., 1996; Chan and Lee, 2005). Work analysis methods have been used in industrialized countries on a larger scale since the 1930s (Laring et al., 2002). Industrial companies and commercial communities have accepted MODAPTS as a valid and useful standard predetermined time system (Agrawal et al., 1990; Cho et al., 2014). Currently, using MODAPTS, the task time can be predicted prior to the task being performed and manual operations for time and motion can be rationalized. In MODAPTS, human motions are classified into twenty-one types, and a constant value is determined as the motion's standard time (Hoffmann and Hui, 2010). However, MODAPTS is complicated with respect to assisting engineers in understanding the system because it requires much more learning time (Cho and Park, 2014).

Compared with traditional PMTS, motion analysis technology possesses the benefits of working efficiently and reliably. Motion analysis takes advantage of computer vision technology and is widely applied to detect, track, and recognize human body motion (Debril et al., 2011; Metaxas and Zhang, 2013; O'Keefe et al., 2014). Motion analysis is considered as one of the challenging problems in many research areas (Mündermann et al., 2006) and has become a hot spot for biomedical engineering (Amir-Khalili et al., 2015), biomechanical studies (Andreoni et al., 2002), virtual reality (Gamberini et al., 2003), advanced user interfaces (Phillips et al., 2005) and smart surveillance system (Elbouz et al., 2015). Mavrikios et al. (2006) applied statistical design of experiments (SDoE) to analyze human motion modeling for car accessibility. However, the models can be applied only to a specific car model. Furthermore, the environmental parameters, like the car's dimensions, influence the human motion paths. However, to the best of our knowledge, motion analysis has not yet been introduced in PMTS. In PMTS, the therbligs, as motion primitives, compose the motion sequence involved in working situations (Dossett, 1992). In this paper, motion analysis technology is achieved using motion primitives, defined to be compositional elements for movement construction (Giszter, 2015), with a PCA-based motion analysis method. With the fundamental assumptions of PMTS and theory of motion primitives, there are possibilities for motion analysis to be introduced into PMTS.

The goal of motion analysis is to represent activities and then analyze motion data for other effects (Ma et al., 2010). To represent human activity, it is essential to create basic behaviors (Slama et al., 2014) that can be regarded as templates or primitives of human activities (Jenkins and Matarić, 2002). Human motion primitives are used to differentiate and segment motions of diverse types in long sequences (Zhang and Sawchuk, 2012). Souvenir and Pless (2005) applied Manifold Clustering to segment simple motions and gain corresponding classifications. Seward and Bodenheimer (2005) demonstrated that it is feasible to reduce dimensions appropriately with isometric feature mapping (ISOMAP), as long as the motion sequence is sufficiently complicated and the result can be logically connected with the motion sequence. However, their research did not make any definitive conclusions about the distance metric based on this work. For walking motions, the distance metric may yield more visually coherent motion. However, for running motions, a smoother motion is preferred. Jenkins and Matarić (2002, 2004) presented another method, spatio-temporal Isomap (ST-ISOMAP), which is an extension of ISOMAP nonlinear dimension reduction, to segment data and employed a spatio-temporal non-linear dimension reduction technique on these segments. ST-ISOMAP provides a means to uncover the spatio-temporal structure. The result is a temporal process structure similar to a Hidden Markov Model. ST-ISOMAP has been successfully applied to human motion and robot teleoperation data.

Human movement is the emergent property of many degrees of freedom (DoF). Several studies have taken multivariate analysis into account to solve the high-dimension problem induced by DoF in human motion (Molenaar et al., 2013). Under such a background, principal components analysis (PCA) has become an extensively used analysis technique in the human motion domain to reduce the dimensions of multivariate data sets and to analyze kinematics (Pinter et al., 2008; Rutherford et al., 2008). Sadler et al. (2010) demonstrated the effectiveness of PCA at identifying differences in lifting kinematics that are adopted when wearing a personal assist-lift device.

This paper explores the contrasting results of segmenting a motion sequence and obtaining the total motion time with MODAPTS. The PCA-based motion analysis, with its efficient segmenting motion sequence and approximate motion primitives compared with MODAPTS, aims to demonstrate the possibility of its application to PMTS. Incorporating motion analysis technology into MODAPTS can help the observer to transfer focus from repeated work primitive segmentation to motion evaluation.

2. Methods and procedures

2.1. MODAPTS

MODAPTS is defined as a procedure for improving productivity and establishing time standards as a result of describing and classifying the motions used or needed to perform a given series of operation and assigning predetermined time standards to these motions (Razmi and Shakhs-Niyaee, 2008). MODAPTS is frequently used in production activities and non-cycle work environments. By analyzing how the work is performed, MODAPTS quantifies the amount of time required to perform an assembly operation. As an analytical approach, efficient MODAPTS can facilitate the accurate time measurement and proactive design process. The most evident feature of MODAPTS is its fundamental simplicity. Although MODAPTS measures work without using a stopwatch, it is accurate enough for setting labor rates in industry. Analyzing safety, estimating direct labor cost, controlling quality and establishing productivity standards are the applications of this system.

MODAPTS is mainly based on the following assumption: all operating actions include some basic actions. The principle of MODAPTS is that all body movements can be expressed by multiples of a simple finger move. MODAPTS analyzes the body motions in sequential assembly operations and translates them into element class codes and time values that are expressed as units called MODs. A MOD value is 129 ms, which is the same as finger moving 2.5 cm (M1). As the experimental results show, the times to act once for other part of the body are integer multiples of MOD. For example, a wrist movement is approximately M2 (2×0.129 s), forearm movement is M3 (3×0.129), whole arm movement is M4