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Construction worker's awkward posture recognition through supervised motion tensor decomposition

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ABSTRACT

Awkward postures in construction activities pose substantial hazards in both instantaneous injuries and long-term work-related musculoskeletal disorders (WMSDs). Posture recognition using motion capturing systems shows promising potential in avoiding and minimizing workers' exposure to awkward postures. However, current motion capturing systems require huge computational resources and complicated processes to recognize postures in construction tasks. To address this issue, we proposed an abstract and efficient motion tensor decomposition approach to compress and reorganize the motion data. Together with a multi-classification algorithm, the proposed approach is able to efficiently and accurately differentiate various postures. To validate the approach, we employed a system based on inertial measurement units (IMUs) to examine two sample activities composed of sequencing postures. The results indicate the proposed approach is able to provide sufficient recognition accuracy with less computation power and memory. Also, the idea of tensorization and tensor decomposition in this paper is extendable to other studies in the construction industry.

1. Introduction

Construction projects involve complex activities and substantial amounts of labor. Execution of this type of work normally requires intense physical movement of laborers' body parts. Such demanding work requirements result in potential instantaneous and long-term injuries to workers. For example, when workers stretch into uncomfortable postures, such as for an overhead installation on top of a ladder, they expose themselves to the instantaneous hazard of a fall. When workers conduct repeated load carrying, kneeling, and twisting tasks, they have the potential to suffer from long-term ergonomic injuries or work-related musculoskeletal disorders (WMSDs) [1]. The majority of these injuries can be attributed to awkward work postures [2]. These postures are frequently observed in the tasks that involve working overhead, kneeling, back bending forward, squatting, neck bending, and reaching. With poor training, workers could frequently experience persistent harm due to incorrect operation of the tasks. To avoid potential injuries, it is crucial to ensure workers master the correct postures in task execution through training and that they are provided with early warnings when they are exposed to potential instantaneous hazards.

This research focuses on proposing a new and efficient posture recognition approach to automatically detect and identify awkward postures. Different from conventional physical skeletal approaches, the proposed method reforms the motion data as high order tensors based on rotation matrices and Euler angles. Without reconstructing the three-dimensional (3D) skeletons, the tensor translates different types of awkward postures as high-dimensional matrices. In addition, to promote the computational efficiency of the posture recognition algorithm, this research introduces a dimension reduction process based on canonical polyadic decomposition (CPD) to extract features from raw motion tensors. An in-lab experiment is conducted to examine the proposed approach and compare the efficiency and accuracy of two-dimensional (2D) motion tensor and 3D motion tensor models. In the experiment, a multi-channel Inertial Measurement Units (IMUs) system is adopted to capture the motion data of various activities. Then the support vector machine (SVM) classification is employed to recognize the derived patterns and validate the detection accuracy. The findings in this research could help enable more realistic and rigorous training programs and foster safer and healthier working behaviors.

2. Background

2.1. Awkward postures and WMSDs

The construction industry is a labor-intensive industry with complicated, unpredictable, and demanding tasks. Dealing with complex interaction among human, machines, and the surrounding environments,

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the premise of construction project success is to ensure safe and healthy working conditions. Among all safety hazards, musculoskeletal disorders or WMSDs are one of the most frequent occupational health issues results in long-term sickness absence [3,4]. In the United States, musculoskeletal disorders account for 32% of all injury and illness cases that result in absence during work days for all industries [5]. In the United Kingdom, an estimated 9,466,000 work days were lost due to WMSDs, an average of 17.1 days lost for each case, which represents 40% of all days lost in the construction industry [6]. Among different construction trades, plasterers, bricklayers and joiners are frequently cited for their high risk [7]. This persistent and ongoing health problem not only leads to loss of productivity, but also comes with a high economic price. In a study on Irish construction workers, Brenner and Ahern conclude musculoskeletal disorders accounted for nearly one third of the conditions leading to permanent disability and early retirement [8]. Similarly, in a study of occupational mobility in a cohort of construction workers, Siebert et al. find disorders of the back and spine is one of the major causes of early retirement due to disability [9]. According to the European Agency for Safety and Health at Work (EU-OSHA)'s report, the costs of absences caused by WMSDs are as high as 2.1 to 3.1% of the total GDP loss [10]. Based on Bhattacharya's estimation, the direct and indirect costs of WMSDs in 2007 were around US$2.6 billion [11]. Moreover, WMSDs can result in various permanent occupational diseases, such as lower-back pain, neck/shoulder pain, tendonitis, and carpal tunnel syndrome, among others [12,13].

Although WMSDs can be attributed to numerous risk factors, the most important among them is awkward body postures [14,15]. Awkward postures refer to body positions that deviate significantly from the neutral position and potentially lead to cumulative trauma disorders [16]. Awkward postures are often associated with conditions such as (1) joint rotations near the end range of motion; (2) activities that require compound rotation of a body joint; and (3) activities that require maintaining muscle force for a long period [16]. Maintaining awkward postures over time results in muscle fatigue and discomfort for a worker and thus the prolonged non-neutral (awkward) posture increases the risk of WMSDs. In essence, awkward postures can be defined as various static postures in construction tasks. In this research, we mainly focus on the awkward postures that include (a) working with the hand(s) above the head (working overhead); (b) bending the knee or ankle to work in a kneeling position (kneeling); (c) bending the back with twisted torso (back bending forward); (d) bending the knee or ankle to work in a squatting position (squatting); (e) bending the neck backward or forward (neck bending); and (f) working with the elbows(s) above the shoulders with hands lower than the head (reaching) (Fig. 1). Among the postures, (a) and (f) are similar to each other, and (c) and (e) are similar to each other. To differentiate them, we define working overhead as the activities that only require upward hand postures, while reaching is defined as the posture with arms pointing to the forward and side directions. Similarly, back bending forward postures involve larger waist rotations, while neck bending postures have a straight body trunk.

A worker's performance in a construction task is associated with the type of postures in the task, duration of each posture and the rest or recover time between postures [17]. Knowing this information, project managers could reduce WMSDs and potential instantaneous hazards through training, intervention, and redesigning the site layout to minimize workers' exposure to awkward postures. For example, through making modifications to workstation layouts to reduce or eliminate low, far, or overhead reaches associated with awkward postures, WMSDs could be significantly relieved [2,18]. Therefore, it is necessary to quantitatively define working postures and identify their durations.

To this end, many researchers categorize the human body into descriptive joint angles [19,20]. With the help of such a definition, a posture could be described by evaluating the angle between adjacent body parts. Such a postural description and identification process is usually called an ergonomic analysis or biomechanical analysis. Over the past 30 years, many ergonomic and posture analysis tools have been developed, such as Quick Exposure Check (QEC) [21] the Assessment of Repetitive Tasks (ART) [22], the Manual Handling Assessment Chart (MAC) [23], the Rapid Upper Limb Assessment (RULA) [24,25], the Rapid Entire Body Assessment (REBA) [26], Washington State's ergonomics rule (WAC 296-62-051) [27], Posture, Activity, Tools and Handling (PATH) [28], Strain Index [29], The Liberty Mutual MMH Tables (SNOOK tables) [30], the NIOSH lifting equation [31,32] and 3D Static Strength Prediction Program (3DSSPP) [33]. The RULA is a postural targeting method for estimating the risks of work-related upper limb injuries based upon the positions of upper arms, wrists, neck, and upper trunk; the REBA estimates the entire body's risks according to the positions of arms, wrists, neck, trunk, and legs. NIOSH lifting equation assesses the postural risks of a worker with regard to major body joints and angles between joints to categorize whether a classified posture is unsafe or safe. All assessment approaches give a quick, systematic, and quantitative assessment of the postural risks of a worker with regard to major body joints and angles between joints. However, these posture assessment approaches usually collect data through observation, questionnaires, or scorecards, which are subject to a subjective bias [34], as well as inefficiency and inaccuracy [35,36]. Therefore, this proposed research aims to an automated approach to quantitatively assess the joints and angles to supplement existing observation and scorecards approaches.

Fig. 1. Typical awkward postures in construction activities.