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Ergonomic analysis of construction worker's body postures using wearable mobile sensors

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A B S T R A C T

Construction jobs are more labor-intensive compared to other industries. As such, construction workers are often required to exceed their natural physical capability to cope with the increasing complexity and challenges in this industry. Over long periods of time, this sustained physical labor causes bodily injuries to the workers which in turn, conveys huge losses to the industry in terms of money, time, and productivity. Various safety and health organizations have established rules and regulations that limit the amount and intensity of workers' physical movements to mitigate work-related bodily injuries. A precursor to enforcing and implementing such regulations and improving the ergonomics conditions on the jobsite is to identify physical risks associated with a particular task. Manually assessing a field activity to identify the ergonomic risks is not trivial and often requires extra effort which may render it to be challenging if not impossible. In this paper, a low-cost ubiquitous approach is presented and validated which deploys built-in smartphone sensors to unobtrusively monitor workers' bodily postures and autonomously identify potential work-related ergonomic risks. Results indicates that measurements of trunk and shoulder flexions of a worker by smartphone sensory data are very close to corresponding measurements by observation. The proposed method is applicable for workers in various occupations who are exposed to WMSDs due to awkward postures. Examples include, but are not limited to industry laborers, carpenters, welders, farmers, health assistants, teachers, and office workers.

1. Introduction

Today's construction projects are becoming more complex and challenging. Construction workers require a wide variety of skills to be able to achieve project goals within specified time, budget, and specifications. Compared to other industries such as manufacturing, construction projects are more labor-intensive. The complexity of tasks often requires workers to go beyond their natural physical limits, or perform repetitive tasks for a long period of time. Over time, such sustained physical demand on workers' bodies may cause health issues and bodily injuries. Work-related injuries of this type are also referred to as Musculoskeletal Disorders (MSDs). Besides their adverse physical implications, MSDs can also lead to significant financial losses. For example, in 2009, direct workers' compensation costs due to MSDs were amounted to more than $50 billion in the U.S. (Liberty Mutual Research Institute For Safety, 2011). To remedy this problem, various health and safety organizations have established rules and guideline to identify the risks associated with performing certain tasks. Such efforts aim at ergonomic design of the workplace to match physical jobs with workers' natural capabilities.

1.1. Work-related Musculoskeletal Disorders (WMSDs)

MSDs are a group of disorders or injuries in a person's inner body parts (e.g. muscles, nerves, tendons, joints, cartilages, and spinal discs) which have relative deformations while he or she moves. Example of MSDs includes Carpal Tunnel Syndrome (CTS), Tendonitis, and Bursitis (Simoneau et al., 1996; Occupational Health Clinics for Ontario Workers Inc, 2017). Work-related Musculoskeletal Disorders (WMSDs) refer to the MSDs due to activities in the workplace associated with physical jobs.

Construction jobs are among the most ergonomically hazardous occupations which involve activities such as manual handling,

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heavy lifting, body twisting, and frequently working in awkward positions, all being potential causes of WMSDs in workers (OSHA, 2000; Health and Safety Executive, 2016). According to the U.S. Department of Labor, construction is one of the six occupations where workers suffer from nonfatal occupational injuries and illnesses (Bureau of Labor Statistics, 2014). The most common types of WMSDs in construction are sprain, strain, CTS, tendonitis, and back pain. In the U.S., 32 construction workers in every 10,000 get injured from a WMSD and take leaves from work (Bureau of Labor Statistics, 2014). Among all trades of construction workers, laborers have the highest rate (45 workers in every 10,000) of getting injured due to WMSDs, with helpers, plumbers, carpenters, and others following (OSHA, 2012). In 2015, the number of days lost due to non-fatal occupational injuries in private construction sites in the U.S. was 79,890, while WMSDs incident rate per 10,000 workers was 34.6 with 13 median days away from work (Bureau of Labor Statistics, 2016). According to the European Labor Force Survey (LFS), in 1999, 4.1 million workers were subjected to WMSDs. In the same year, 3158 in every 100,000 workers in the construction sector suffered from WMSDs, and in 1292 cases, workers took 14 or more days of leave of absence from work (European Agency for Safety and Health at Work, 2010). According to the Liberty Mutual Workplace Safety Index, in 2009, WMSDs caused by overexertion resulted in $12.75 billion in workers' compensation costs which was 25.4% of all compensation costs (Liberty Mutual Research Institute For Safety, 2011). These and similar figures provide a glimpse into the loss of productivity at construction sites due to WMSDs. This has also intrigued researchers to explore ways to ergonomically prevent WMSD-related hazards.

According to the Occupational Safety and Health Administration (OSHA), there are eight risk factors related to WMSDs including force, repetition, awkward postures, static postures, quick motion, compression or contact stress, vibration, and extreme temperatures (OSHA, 2000). Most often, awkward postures can be prevented by rearranging the workplace or selecting proper tools for workers. But different jobs are associated with different types of risks and the challenge is to identify the correct ergonomic risks associated with a particular job. A thorough job hazards analysis (JHA) can identify the risks at the workplace, but it may be challenging to carry out the analysis because of complexity of the job and the manual effort needed to monitor work processes (Alwasel et al., 2011). Therefore, the objective of this paper is to present a methodology to facilitate the process of unobtrusively monitoring body postures of workers to autonomously assess and preempt potential risk factors.

2. Prevention through design (PTD) and risk assessment

Prevention through Design (PtD) is an initiative taken by the National Institute for Occupational Safety and Health (NIOSH). It encompasses a host of efforts to anticipate and design out ergonomic-related hazards in facilities, work methods, operations, processes, equipment, tools, products, new technologies, and the organization of work (NIOSH, 2014a). The goal of the PtD initiative is to prevent and control occupational injuries, illnesses, and fatalities. According to NIOSH, this goal can be achieved by: 1) eliminating or reducing potential risks to workers to an acceptable level at the source or as early as possible in a project life cycle, 2) including design, redesign, and retrofit of new and existing work premises, structures, tools, facilities, equipment, machinery, products, substances, work processes, and the organization of work, and 3) enhancing the work environment through enabling the prevention methods in all designs that affect workers and others on the premises.

A proper PtD practice requires prior identification of the risk factors on a jobsite which in turn, necessitates that work-related data be adequately collected, and subsequently used in an integrated risk assessment framework. In general, three different data collection approaches have been practiced for identifying risk factors: 1) self-assessment, where workers are asked to fill out a form to identify the risk levels associated with their tasks, 2) observation, where a job analyst assesses the risk factors by observing the jobsite in real time or via a recorded video, and 3) direct measurement, where instruments are used to measure postures directly (NIOSH, 2014b).

1. In the self-assessment approach, data are collected on both physical and psychosocial factors through interviews and questionnaires (David, 2005). This approach has relative advantages of having low initial cost, being straightforward to use and applicable to wide range of workplace situations (David, 2005). However, since a large number of samples are required to ensure that collected data are representative of the group of workers, subsequent costs for analysis and the required skills for interpreting the findings are generally high (David, 2005). Moreover, researchers have stated that workers' self-assessments on exposure level are often imprecise, unreliable, and biased (Viikari-Juntura et al., 1996; Balogh et al., 2004; Spielholz et al., 2001).
2. Observation-based approach is a simpler method that includes real-time assessment of exposure factors by systematic evaluation of the workers on the jobsite (Teschke et al., 2009). Despite being inexpensive and practical for a wide range of work situations, this method is disruptive in nature, and is subjected to intra- and inter-observer variability (David, 2005). An advanced method of observation-based assessment includes analyzing recorded video (Mathiassen et al., 2013; Dartt et al., 2009) which allows for more exposure factors to be obtained, but is mostly impractical due to the substantial cost, time, and technical knowledge required (David, 2005).
3. Unlike the previous two approaches, direct measurement uses tools attached to workers' bodies to collect data. Examples of this type of approach include but are not limited to using magneto-resistive angle sensors to measure shoulder flexion (Alwasel et al., 2011), Kinect or depth sensors to analyze posture by detecting position of skeleton joints at high sampling rates (Diego-Mas and Alcaide-Marzal, 2014; Plantard et al., 2015; Más et al., 2014), and smartphone's built-in accelerometer and gyroscope sensors to measure arm inclination (Yang, 2015). Previous work in this area has revealed that the direct measurement approach yields the most valid assessment of risk factors compared to other approaches (Kilbom, 1994; Winkel and Mathiassen, 1994). Building on previous work from multiple disciplines, in this research, a methodology is designed and validated to accurately identify a worker's body postures while carrying manual work. Ultimately, the findings of this research are sought to contribute to the PtD's mission by enabling construction researchers and decision-makers to design field activities to eliminate (or significantly reduces) work-related ergonomics issues for construction workers.

2.1. *Risk assessment of construction tasks associated with awkward postures*

For the purpose of identifying risks associated with awkward postures, generally, postures of different body parts (e.g. trunk, shoulder, and elbow) are measured in terms of degree of bent from the neutral posture. A neutral posture occurs when a worker needs minimum effort for standing (i.e. standing straight with his or her