ARTICLE IN PRESS

Automation in Construction xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Automation in Construction

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

An experimental study of real-time identification of construction workers' unsafe behaviors

Yantao Yu[a], Hongling Guo[a,*], Qinghua Ding[b], Heng Li[c], Martin Skitmore[d]

[a] Department of Construction Management, Tsinghua University, Beijing, China
[b] Department of Computer Science and Technology, Tsinghua University, Beijing, China
[c] Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong
[d] School of Engineering and Built Environment, Queensland University of Technology (QUT), Australia

ARTICLE INFO

Keywords:
Construction safety
Construction workers
Unsafe behavior
Motion capture
Behavior identification and recognition

ABSTRACT

Construction workers' unsafe behavior is one of the main reasons leading to construction accidents. However, the existing management approach to unsafe behaviors, e.g. Behavior-Based Safety (BBS), relies primarily on manual observation and recording, which not only consumes lots of time and cost but impossibly cover a whole construction site or all workers. To solve this problem and improve safety performance, an image-skeleton-based parameterized method has been proposed in a previous research to real-time identifying construction workers' unsafe behaviors. A theoretical framework has been developed with a preliminary test, but still lacking a comprehensive experiment to verify its validity, particularly in the recognition of the types of unsafe behaviors. This will have a serious impact on the extensive application of the method in real construction sites. Based on the method, this research designs and carries out a series of experiments involving three types of unsafe behaviors to examine its feasibility and accuracy, and determines the value ranges of relevant key parameters. The results of the experiment demonstrate the feasibility and efficiency of the method, being able to identify and distinguish unsafe behaviors in real time, as well as its limitations. This research not only benefits the extensive application of the method in construction safety management, but improves the effectiveness and efficiency of the method by identifying relevant future research focuses. Therefore this paper contributes to the practice as well as the body of knowledge of construction safety management.

1. Introduction

Nearly 80% of construction accidents are caused by workers' unsafe behaviors [25]. It is necessary and important for project managers or safety managers to monitor workers' unsafe behaviors in construction sites. Behavior-Based Safety (BBS) is regarded as a promising approach to managing unsafe behaviors on site [25,26]. BBS needs the observation and identification of on-site unsafe behaviors and then makes a feedback to jobsite workers [2,4,6,19,41]. However, this mainly depends on manual observation and recording, which not only consumes lots of time and cost but also impossibly cover a whole construction site or all workers [10], therefore limiting its extensive application in the construction industry.

Automation technologies have been proposed to monitor construction workers' behaviors in construction sites so as to improve the efficiency and effectiveness of unsafe behavior management [9,34,35]. For example, wearable sensors and motion capture technologies have been adopted in existing research [24,26,36]. The former is sensitive and in time, but affecting workers' normal working or operations [3,23,37,38]. The latter is usually to collect workers' behavior images with cameras and then identify unsafe behaviors by comparing the captured images with the images in unsafe behaviors databases [5,18,28,29,32,39]. The motion capture method requires no wearable devices, but not timely enough, as comparing the similarity of images is of great calculation amount [20,21,29,31,38,42].

Motion capture technologies have arisen the interest of the construction industry, being mainly used in the identification and biomechanical analysis of unsafe behaviors [15,33]. These methods usually contain four steps: 1) collecting sample data (joint sensor data, RGB-D image and stereo camera image), 2) reducing dimension, 3) extracting the features of motions from the sample data, and 4) identifying test motions by comparing their features with the features in Step 3 [7,11,12,14,22,27,32]. Most of these methods are post-analysis, thus not being applied to the real-time identification of unsafe behaviors. The main reason lies in the dimension reduction method. In order to reduce the redundant dimensions of images, previous studies used to

* Corresponding author.
E-mail address: hlguo@tsinghua.edu.cn (H. Guo).

http://dx.doi.org/10.1016/j.autcon.2017.05.002
Received 31 July 2016; Received in revised form 7 April 2017; Accepted 8 May 2017

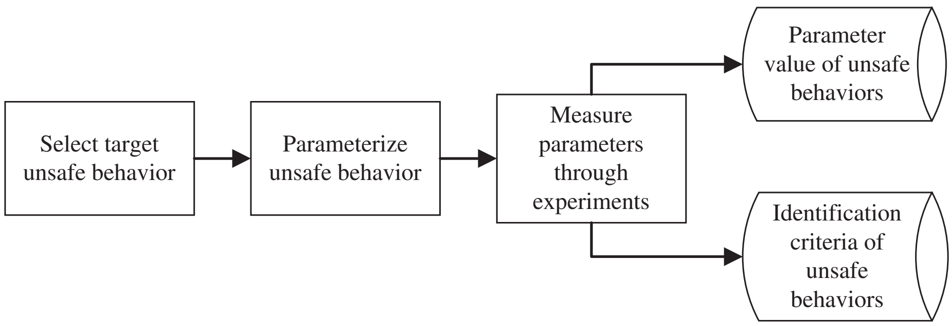


Fig. 1. Experiment process.

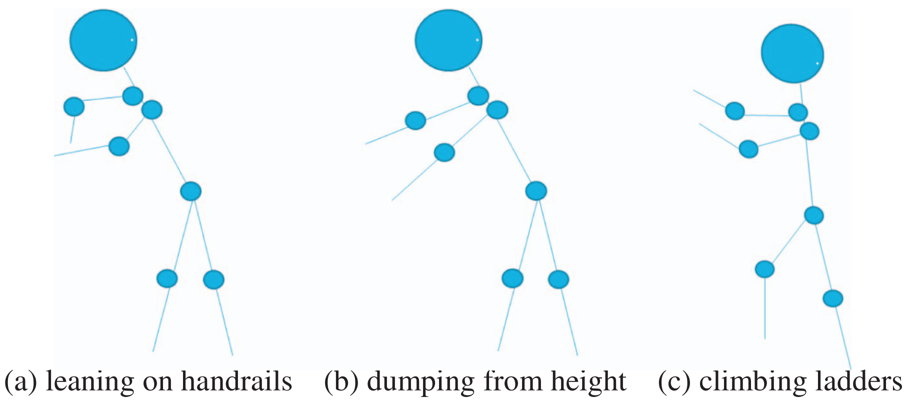


Fig. 2. The skeleton models of the leading postures of three unsafe behaviors.

Table 1
Key joint parameters in human skeleton mathematical model.

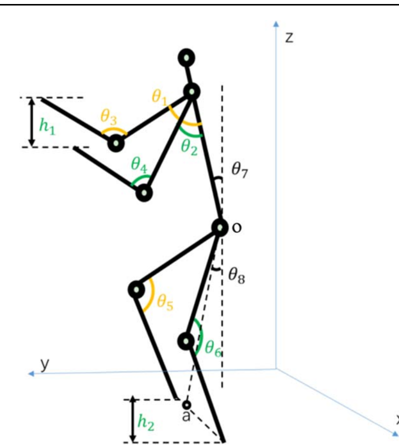
No.	Abbr.	Description	Skeleton model
θ1	LA	Angle between left arm and torso	
θ2	RA	Angle between right arm and torso	
θ3	LE	Angle of left elbow	
θ4	RE	Angle of right elbow	
θ5	LK	Angle of left knee	
θ6	RK	Angle of right knee	
θ7	UB	Inclination of upper body (Angle between torso and axis z)	
θ8	LB	Inclination of lower body (Angle between line a-o and axis z. Point a is the middle point of the connecting line between two feet; Point o is located at the hip joint.)	
h1	WH	The height difference between two wrists	
h2	AH	The height difference between two ankles	

Fig. 3. Kinect for Windows 2.0.

adopt machine learning methods, such as Kernal PCA and DTW methods [13,14]. However, this leads to long latency time since it took a lot of time to calculate the value of these features, especially in the case of dynamic behavior rather than static posture [8,11,13,14,23].To solve the above problems, a simplified image-based unsafe behavior identification method has been developed and tested with one behavior (climbing) of one worker by the authors. The preliminary study shows that it is feasible to real-time identify workers' unsafe behaviors through the simplification of behavior data and the development of a concise identification algorithm. However, various kinds of unsafe behaviors (e.g. dumping, leaning, etc.) are involved in a construction site with different characteristics, which mean different key parameters to describe these behaviors. Even for a same behavior with the same key parameters, different workers may present different value range for