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Applying Physiological Status Monitoring in Improving Construction Safety Management

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Abstract

A variety of research has highlighted the importance of improving safety in the construction industry. Due to the attributes of construction activities (e.g., inappropriate shiftwork and schedules) and sites (e.g., darkness, narrowness), human errors frequently cause construction accidents, especially when construction workers suffer from mental and/or physical fatigue. To address this problem, this study proposes an approach based on Physiological Status Monitoring (PSM). By detecting brain wave rhythms and Heart Rate Variability (HRV) of workers, the proposed approach could analyze fatigue levels. After identifying risks of fatigue, the proposed approach notifies the fatigued workers as well as transfers relevant statistics to construction managers. The managers, therefore, are able to supervise their workers in real time. Given the results of on-site tests, construction safety management is enhanced, while the construction accidents caused by mentally and/or physically fatigued workers are circumvented as quickly as possible. Consequently, this study is a useful reference for similar applications in many countries.

Keywords: *brain-computer interface, construction safety management, fatigue, heart rate variability, information technology, positioning, physiology*

1. Introduction

Construction accidents occur frequently around the world. For example, in 2006, Ling *et al.* (2009) reported that the construction fatality rates in the United Kingdom, United States, and Singapore were 3.7, 4.1, and 9.4 per 100,000 persons employed, respectively. At least 9,000 accidents occurred from 2002 to 2011 in the U.S. construction industry alone (Chi *et al*., 2015), while the Taiwanese construction industry had more than 1,000 accidents from 2000 to 2009 (Cheng *et al*., 2012). In South Korea, an occupational accident report documented that the number of accidents in the construction industry was 25% higher than it was in all industries in 2012 (Seo *et al*., 2015). These studies highlight the importance of improving the safety at construction sites.

To prevent the potential of construction accidents, Information Technology (IT) based approaches have become popular. These approaches include monitoring construction sites to record sudden disasters (Park *et al*., 2012), auditing construction activities for risk assessment (Zhang *et al.*, 2013), tracking construction workers in dangerous working areas (Costin *et al.*, 2012), holding regular training and exercises to establish safety concepts (Cheng *et al.*, 2012), improving the necessary equipment to offer complete protection (Kelm *et al*., 2013), analyzing working postures to identify unsafe behaviors (Cheng *et al.*, 2013), detecting moving objects to avoid unexpected collisions (Lai and Kang, 2009), and applying unmanned vehicles to finish perilous working processes (Yu *et al*., 2014). As a result, on-site safety is ensured.

Recently, after investigating the causes of construction accidents, many researchers have argued that human errors are the key, especially when construction workers suffer from mental and/or physical fatigue. However, few studies have focused on on-site fatigue risks. Thus, this study proposes a different approach, which allows automatic examination of fatigue levels of workers in real time, through the use of Physiological Status Monitoring (PSM), including brain wave rhythms and Heart Rate Variability (HRV). When fatigued workers are identified, the proposed approach would involve notifying these workers and construction managers. Because of the detailed information of the workers, such as their names and locations, managers are able to assist them to address the fatigue, such as taking a rest or receiving massage therapy, thus decreasing human-made construction accidents as soon as possible.

The remainder of this paper is organized as follows: Section 2 reviews prior studies regarding IT-based approaches for the avoidance of construction accidents; Section 3 explains the research gap; Section 4 describes the proposed approach and its implementation; Section 5 provides the results of the on-site tests; Section 6 discusses findings and limitations of the

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approach; and Section 7 concludes the study. In sum, this study successfully helps to increase the efficiency of construction safety management in the construction industry.

2. Literature Review

Based on various construction regulations, Langford *et al.* (2000) proposed a model to identify safety behavior and management in the construction industry. This model showed that construction safety management requires a self-regulatory context, including how well and how frequently safety inspections execute, how information regarding risks and safety is delivered, and how the safety of participants is managed. Thus, in the past decades, depending on manual observation at construction sites, construction managers spent a significant portion of time maintaining construction safety. In contrast, IT-based approaches offer numerous advantages, including rapid information access, active information transmission, clear information representation, and convenient information storage. Many researchers have illustrated their achievements when applying these approaches in the three stages of construction accidents, including:

- Before the accidents: It is necessary to discover any possible factors that may lead to accidents so that that these accidents could be prevented. Park *et al.* (2012) developed a camera system to reach three-dimensional tracking of construction resources, including steel plate, workers, and vans. Zhang *et al.* (2013) automated safety checking for Building Information Models (BIM) to perform fall-related measurements before construction activities started. Due to the uncertain environmental information in the craning, conveying, and excavating, Yu *et al.* (2014) designed a mobile robot controlled by the "just-in-time" gesture tracking technique.
- During the accidents: To smoothly respond to accidents that have occurred, grasping on-site emergency status is fundamental. Through a Geographic Information System (GIS) and new algorithm, Liu *et al.* (2006) reduced the response time of fire accidents in infrastructure and transportation projects. Since the passive Radio Frequency Identification (RFID) technique was adopted in a high-rise renovation project, Costin *et al.* (2012) argued that the locations of on-site workers could be easily detected during accidents. Tsai (2014[1]) proposed a mobile augmented-reality (AR) based approach to streamline the fragmented information representations involved in emergency scenarios.
- After the accidents: When the injured workers are rescued, recovering the site is of primary importance at this stage. Meantime, it is important to acquire expertise and information from these accidents to avoid similar accidents in the future. Tadokoro *et al.* (2009) developed a robot to gather image information at narrow voids 7 meters into in a completely crushed parking building under construction. Cheng *et al.* (2012) used the data mining method in a big database and predicted the occurrence rules for falls and collapses in construction projects. Gheisari *et al.* (2014) described the potential of unmanned aerial systems (UAS) at construction sites, which could evaluate the possible damage caused by accidents.

3. Problem Statement

Regarding human-made construction accidents, fatigue is often defined as the main factor (Garrett and Teizer, 2009). During a construction project, construction workers have to mentally and physically participate in ongoing activities. Because of various factors, such as the light, noise, and air at the sites; the ages, sex, and life styles of the workers; and the tasks, stress, and working hours with the activities, the workers always suffer from mental (i.e., a sensation of weariness) and/or physical (i.e., a painful phenomenon associated with overstressed muscles) fatigue (Grandjean, 1979). Such workers have a feeling of exhaustion, lowered physiological functions, a breakdown of autonomic nervous balance, and even a decrease in their work efficiency (Saito, 1999).

Although objective (e.g., skin conductance, oxygen consumption, facial expression) and subjective (e.g., questionnaires including Fatigue Assessment Inventory [FAI] and Fatigue Index Score [FIS]) measurements are available to assess the fatigue levels of the workers (Fang *et al.*, 2015), the ability to determine the fatigued workers at construction sites in real time is rare. For example, regarding falls in construction activities, the tight relationship between loss-of-balance and fatigued workers has been verified (Hsiao and Simeonove, 2001). Some studies have been able to detect falling workers during or after the accidents (Tsai, 2014[2]). In contrast, very few studies have observed falls by monitoring the current physiological status of the workers. In other words, very few approaches could comprehend the falls of fatigued workers ahead of time and avoid these accidents.

4. Approach

The anticipated purpose of this study is to understand who and where the fatigued workers are at construction sites. When construction workers are monitored, the proposed approach adopts the electroencephalogram (EEG), electrocardiography (ECG), and positioning techniques, which is a record of voltage difference between various points on the head's surface, determines the electrical activity within the heart, and illustrates the locations of targets, respectively. The results of such measurements, compared with those of the subjective measurements, are more credible (Ju *et al.,* 2012). Also, the time-consuming analysis of the collected questionnaires via statistical tools could be simplified.

Brains manage the cognitive functions in humans. Depending on the working frequencies in brains, at least four types of brain wave rhythms can be identified in EEG. These are the delta (1-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), and beta (13-30 Hz) rhythms, respectively. For a mentally fatigued human, many researchers indicated that the occurrence of the alpha rhythm

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increases, especially the lower alpha rhythm (8-10 Hz) (Lal and Craig, 2001; Trejo *et al.*, 2015). Because of such physiological characteristic, this study applies a portable device (Fig. 1) associated with a brain-computer interface (BCI) to capture the lower alpha rhythm of construction workers from their left foreheads (NeuroSky, 2016), and confirm whether the workers are suffering from mental fatigue.

In addition to the brain, the heart is another important human organ. Although the Heart Rate (HR) continues, the time between two beats (i.e., an R-R interval) differs, even when the HR is stable. HRV, which examines the beat-to-beat variations in normal R-R intervals, serves as a useful parameter for managing physical fatigue in ECG (Achten and Jeukendrup, 2003; Makivic *et al*., 2013). A high HRV is associated with high oxygen uptake, while a low HRV is accompanied with increased mortality (Achten and Jeukendrup, 2003). Due to the complicated morphology of ECG, photoplethysmography (PPG), which assembles an infrared emitter to detect the amount of blood pumped into the aortic valve during ventricular depolarization, is an alternative for similar applications (Bolanos *et al*., 2006). Thus, in the proposed approach (Fig. 1), this study configures a PPG-based wearable device (Garmin, 2016) to evaluate the HRV of the workers and identify whether the workers have physical fatigue.

After identifying the mentally and/or physically fatigued workers, the proposed approach needs to define their locations through positioning techniques, such as Global Positioning Systems (GPS), Ultra Wide Band (UWB), and wireless networks. Because workers may stay in outdoor or indoor areas, the proposed approach adopts a combination of GPS and wireless networks-based positioning techniques. Considering that the BCI and HRV devices support wireless data transmission via Bluetooth and the workers have difficulty carrying on heavy operation devices, this study develops the proposed approach using the Google Android-based mobile phones (Fig. 1).

Figure 2 shows the flowchart of the on-site implementation of the proposed approach. First, construction workers wear the BCI devices on their heads, the heart rate monitor (HRM) devices on their chests, and the HRV devices on their hands. To obtain the individual baseline of the workers' current physiological status, the workers should stand in a position quietly for five minutes before construction activities. After the workers start construction processes, a mechanism (i.e., a fatigue analyzer) monitors the changes of their physiological status (Fig. 3). When mentally fatigued workers are identified (i.e., the number of times the occurred lower alpha rhythm reaches 400 times within 10 minutes), the mobile phones would vibrate and make a sound to alert these workers.

Moreover, the fatigue analyzer could synchronously determine which workers are physically fatigued (Fig. 3). While the workers perform construction processes, their HRV changes. If the HRV continues to be lower than the baseline and leads to a

Fig. 1. The Devices used in the Proposed Approach

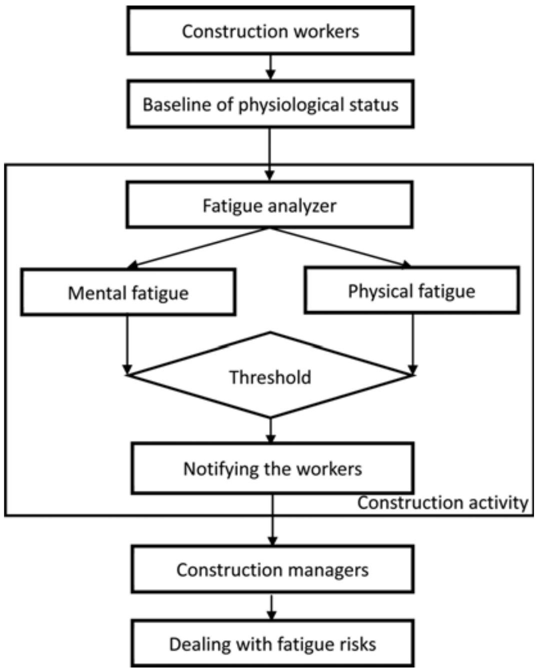

Fig. 2. Flowchart for the Proposed Approach

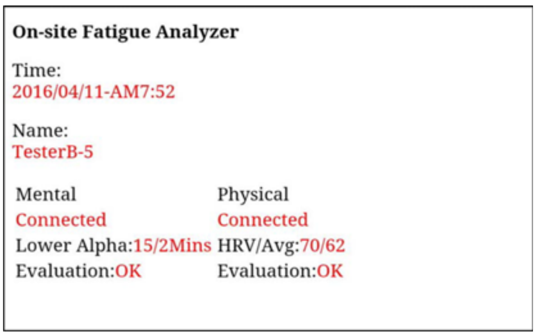

Fig. 3. Analyzing the Fatigue Levels of the Workers

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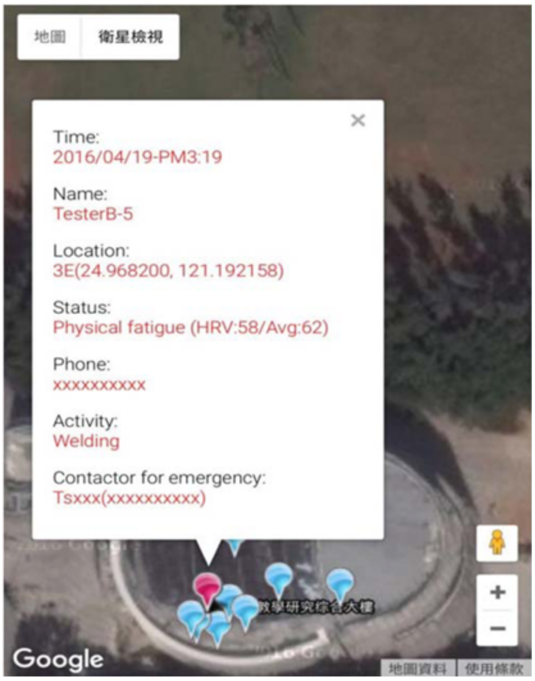

Fig. 4. Showing the Fatigued Workers

downward pointing, the bodies of the workers experience significant fatigue (ithlete, 2016). In consequence, when a construction worker maintains such a condition within 10 minutes, the fatigue analyzer identifies that this worker is suffering from physical fatigue. The worker, then, gets an alarm, which asks him/her to take a rest. The fatigue analyzer also would deliver alerts to construction managers (Fig. 4), which detail the information regarding the fatigued workers, including their names, locations, physiological status, activities, phone numbers, and contactors for emergency. The managers could immediately move to these workers and make responses.

5. Tests

This study executed several on-site tests to understand the performance of the proposed approach. For a construction project, 22 male participants engaged in the tests, including two 40-year-old construction managers and 20 construction workers aged from 25 to 32 years old. Participants could immerse themselves in this study because the results of the tests did not affect their original rights, such as salaries and promotions. During the period of eight hours per working day, the workers moved, trimmed, bended, welded, and assembled steel bars on the same construction floor with sufficient air and light.

This study randomly divided the participants into control and experimental groups. Over the course of two weeks, a manager manually observed 10 workers in the control group, while the other manager adopted the proposed approach to monitor the other 10 workers in the experimental group. When the fatigued workers were detected in both groups, the managers would require the workers to obtain subjective ideas regarding fatigue feelings. Meantime, the managers checked the construction activities to judge the potential of construction accidents. Table 1 lists the results of the tests, including:

- Identified fatigue risks: Associated with manual inspection, the control group identified five cases (three in the first week and two in the second week). In the experimental group, the proposed approach reported 116 (113 regarding mental fatigue and three regarding physical fatigue) and 144 (142 regarding mental fatigue and two regarding physical fatigue) cases in the first and second weeks, respectively. Based on the comparison between the two groups, the proposed approach found more fatigue risks than manual inspection. More importantly, the proposed approach could classify these risks into mental and physical fatigue. The results also revealed the difficulty of visually observing the workers who are suffering from mental and/or physical fatigue.
- Collected subjective feelings: In the control group, the workers confirmed two cases regarding on-site fatigue risks during the first week; however, none occurred in the second week. When the manager correctly arrived at the locations of the fatigued workers in the experimental group, the workers agreed with the 142 cases regarding the mental fatigue (69 and 73 cases in the first and second weeks, respectively) and four cases regarding the physical fatigue (three and one cases in the first and second weeks, respectively). Although both control and experimental groups demonstrated the gap between the identified fatigue risks and subjective feelings, the proposed approach still recognized more fatigue risks than the manual inspection. Thus, the proposed approach helped to manage the fatigued workers.
- Potential of on-site accidents: After auditing the construction activities associated with the fatigued workers in the control group, the manager pointed out one case related to construction safety. In this case, the worker placed the weld-

Table 1. Results of the Tests

	Control group		Experiment group			
	Manual inspection		Proposed approach			
	1st week	2nd week	1st week		2nd week	
			Mental	Physical	Mental	Physical
Identified fatigue risks	3	2	113	3	142	2
Collected subjective feelings	2	0	69	3	73	1
Potential for on-site accidents	1	0	3	1	2	1

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ing facilities and flammable construction materials together, which may lead to an accidental fire. In the experimental group, the manager claimed, in total, five cases regarding mental fatigue risks (three and two in the first and second weeks, respectively) and two cases regarding the physical fatigue risks (each in the first and second weeks, respectively), which may cause construction accidents. Two of these cases were particularly serious. One case was that a worker was drunk on alcohol and generated the same appearance as mental fatigue, while the other was a physically fatigued worker suffering from heat exhaustion. The rest of the cases were disorderly handling of construction tools, which may conduct fall-down accidents. Obviously, compared to manual inspection, the efficiency of construction safety management through the proposed approach is better.

6. Discussion

The aforementioned tests and results explained the main feature of the proposed approach. Manual inspection on managing on-site fatigue risks was subjective and inefficient. In contrast, this approach monitored the physiological status of many construction workers objectively and synchronously. While the managers were unnecessarily close to the workers, the approach still successfully determined the mentally and/or physically fatigued workers. Based on the detailed status of the fatigued workers, the managers timely responded to such workers.

However, four limitations require further improvement, including:

- Sensitivity of the proposed approach: This study examined the potential of the proposed approach for construction safety management. However, when the threshold of the fatigue analyzer in this approach changes, the test results differ. Thus, exploring the relationship between the fatigue analyzer and the fatigued workers will be vital in the future. Also, integrating several PSM mechanisms into the proposed approach may allow construction managers to effectively perform construction safety management based on various different factors.
- Comfort of the used PSM devices: During this study, some participants in the experimental group claimed that wearing the PSM devices was not comfortable, especially during hot weather in summer. For example, because of sweat, the BCI devices slipped, while the HRM and HRV devices became adhesive. When the participants adjusted the wearing positions of these devices, the accuracy of the proposed approach may be affected. For the recognized conditions, modifying the PSM devices to correspond to ergonomics is necessary, such as sticking waterproofing surgical tape or using talcum powder around the regional skin contacting with the PSM devices.
- Distribution of the delivered alerts: When the proposed approach detects fatigued workers during the identical period, a construction manager would receive several alerts at once. However, this manager had difficulty coping with these alerts simultaneously, especially for emergent conditions, such as one of the fatigued workers falling into unconsciousness. Thus, enabling other workers nearby the fatigued workers to obtain the alerts is a solution, since the manager could assign available workers to check the status of the fatigued workers. In other words, optimizing the delivery of the alerts may reduce the response time during various emergency scenarios.
- Solutions for the fatigue risks: Although construction managers could identify whether construction workers suffer from mental and/or physical fatigue in the proposed approach, they may have no solutions for improving the fatigue levels of the workers. For such a problem, if the proposed approach could offer suggestions based on the fatigue status and classification of the workers, the performance of the proposed approach could be perfected. Also, when the fatigued workers take a rest, the managers should carefully check the construction schedule again because the productivity of the ongoing activities may change.

7. Conclusions

In contrast with various industries, the construction industry has more frequent accidents. Improving the efficiency of construction safety management has become imperative. Based on the causes of these accidents, several research studies have highlighted that mentally and/or physically fatigued workers were prone to lose focus and generate errors in construction projects. Thus, various IT-based approaches have been applied in managing on-site fatigue risks. However, these approaches focused on the exterior behavioral phenomenon of construction workers.

Unlike in prior studies, this study proposed a PSM-based approach to evaluate the interior physiological appearances of the workers. During the tests, by examining the brain wave rhythms and HRV of the workers, the approach identified their fatigue levels in real time. Also, the approach was efficient when a quantity of the workers were monitored together at construction sites. If the workers suffered from mental and/or physical fatigue, the approach notified them and their managers. The mentally fatigued workers would be awakened, while the physically fatigued workers would be asked to take a rest. Due to the clearly described details of the fatigued workers, the managers moved to the locations of these workers and confirmed their status. The potential of construction accidents could be minimized. Overall, construction safety management in the construction industry could benefit from this study.

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References

Achten, J. and Jeukendrup, A. E. (2003). "Heart rate monitoring." *Sports medicine*, Vol. 33, No. 7, pp. 517-538, 10.2165/00007256-200333070-00004.

Bolanos, M., Nazeran, H., and Haltiwanger, E. (2006). "Comparison of heart rate variability signal features derived from electrocardiography and photoplethysmography in healthy individuals." In: *Proceedings of the 28th EMBS Annual International Conference*, United States, 10.1109/IEMBS.2006.4398399.

Cheng, C. W., Leu, S. S., Cheng, Y. M., Wu, T. C., and Lin, C. C. (2012). "Applying data mining techniques to explore factors contributing to occupational injuries in Taiwan's construction industry." *Accident Analysis and Prevention*, Vol. 48, pp. 214-222, DOI: 10.1016/j.aap.2011.04.014.

Cheng, T., Migliaccio, G. C., Teizer, J., and Gatti, U. C. (2013). "Data fusion of real-time location sensing and physiological status monitoring for ergonomics analysis of construction workers." *Journal of Computing in Civil Engineering*, Vol. 27, No. 3, pp. 320-335, DOI: 10.1061/(ASCE)CP.1943-5487.0000222.

Chi, S., Han, S., Kim, D. Y., and Shin, Y. (2015). "Accident risk identification and its impact analyses for strategic construction safety management." *Journal of Civil Engineering and Management*, Vol. 21, No. 4, pp. 524-538, DOI: 10.3846/13923730.2014.890662.

Costin, A., Pradhananga, N., and Teizer, J. (2012). "Leveraging passive RFID technology for construction resource field mobility and status monitoring in a high-rise renovation project." *Automation in Construction*, Vol. 24, pp. 1-15, DOI: 10.1016/j.autcon.2012.02.015.

Fang, D., Jiang, Z., Zhang, M., and Wang, H. (2015). "An experimental method to study the effect of fatigue on construction workers' safety performance." *Safety Science*, Vol. 73, pp. 80-91, DOI: 10.1016/j.ssci.2014.11.019.

Garmin (2016). *Specification of Fenix 3 HR*, Taiwan.

Garrett, J. W. and Teizer, J. (2009). "Human factors analysis classification system relating to human error awareness taxonomy in construction safety." *Journal of Construction Engineering and Management*, Vol. 135, No. 8, pp. 754-763, DOI: 10.1061/(ASCE)CO.1943-7862.0000034.

Gheisari, M., Irizarry, J., and Walker, B. (2014). "UAS4SAFETY: The potential of unmanned aerial systems for construction safety applications." In: *Construction Research Congress 2014*, pp. 1801-1810, United States, DOI: 10.1061/9780784413517.184.

Grandjean, E. (1979). "Fatigue in industry." *British Journal of Industrial Medicine*, Vol. 36, No. 3, pp. 175-186.

Hsiao, H. and Simeonov, P. (2001). "Preventing falls from roofs: A critical review." *Ergonomics*, Vol. 44, No. 5, pp. 537-561, DOI: 10.1080/00140130110034480.

ithlete (2016). *Monitoring Heart Rate Variability (HRV) is so much more valuable than just monitoring heart rate*, United Kingdom.

Ju, O. Y., Il, J. T., Meiling, L., and Hee, L. Y. (2012). "A study on fatigue measurement of operators for human error prevention in NPPs." In: *Transactions of the Korean Nuclear Society Autumn Meeting*, Gyeongju, Korea.

Kelm, A., Laußata, L., Meins-Becker, A., Platz, D., Khazaee, M. J., Costin, A. M., Helmus, M., and Teizer, J. (2013). "Mobile passive Radio Frequency Identification (RFID) portal for automated and rapid control of Personal Protective Equipment (PPE) on construction sites." *Automation in Construction*, Vol. 36, pp. 38-52, DOI: 10.1016/j.autcon.2013.08.009.

Lai, K. C. and Kang, S. C. (2009). "Collision detection strategies for virtual construction simulation." *Automation in construction*, Vol. 18, pp. 724-736, 10.1016/j.autcon.2009.02.006.

Lal, S. K. L. and Craig, A. (2001). "A critical review of the psychophysiology of driver fatigue." *Biological psychology*, Vol. 55, pp. 173-194, DOI: 10.1016/S0301-0511(00)00085-5.

Langford, D., Rowlinson, S., and Sawacha, E. (2000). "Safety behaviour and safety management: Its influence on the attitudes of workers in the UK construction industry." *Engineering, Construction and Architectural Management*, Vol. 7, No. 2, pp. 133-140, DOI: 10.1108/eb021138.

Ling, F. Y. Y., Liu, M., and Woo, Y. C. (2009). "Construction fatalities in Singapore." *International Journal of Project Management*, Vol. 27, No. 7, pp. 717-726, DOI: 10.1016/j.ijproman.2008.11.002.

Liu, N., Huang, B., and Chandramouli, M. (2006). "Optimal siting of fire stations using GIS and ANT algorithm." *Journal of Computing in Civil Engineering*, Vol. 20, No. 5, pp. 361-369, DOI: 10.1061/(ASCE)0887-3801(2006)20:5(361).

Makivic, B., Nikic, M. D., and Willis, M. S. (2013). "Heart Rate Variability (HRV) as a tool for diagnostic and monitoring performance in sport and physical activities." *Journal of Exercise Physiology*, Vol. 16, No. 3, pp. 103-131.

NeuroSky (2016). *Experience today's most affordable EEG headsets*, NeuroSky, United States.

Park, M. W., Koch, C., and Brilakis, I. (2012). "Three-dimensional tracking of construction resources using an on-site camera system." *Journal of Computing in Civil Engineering*, Vol. 26, No. 4, pp. 541-549, DOI: 10.1061/(ASCE)CP.1943-5487.0000168.

Saito, K. (1999). "Measurement of fatigue in industries." *Industrial health*, Vol. 37, No. 2, pp. 134-142, DOI: 10.2486/indhealth.37.134.

Seo, H. C., Lee, Y. S., Kim, J. J., and Jee, N. Y. (2015). "Analyzing safety behaviors of temporary construction workers using structural equation modeling." *Safety Science*, Vol. 77, pp. 160-168, DOI: 10.1016/j.ssci.2015.03.010.

Tadokoro, S., Murphy, R., Stover, S., Brack, W., Konyo, M., Nishimura, T., and Tanimoto, O. (2009). "Application of active scope camera to forensic investigation of construction accident." In: *IEEE Workshop on Advanced Robotics and its Social Impacts*, Japan, DOI: 10.1109/ARSO.2009.5587076.

Trejo, L. J., Kubitz, K., Rosipal, R., Kochavi, R. L., and Montgomery, L. D. (2015). "EEG-based estimation and classification of mental fatigue." *Psychology*, Vol. 6, pp. 572-589, DOI: 10.4236/psych.2015.65055.

Tsai, M. K. (2014[1]). "Streamlining information representation during construction accidents." *KSCE Journal of Civil Engineering*, Vol. 18, No. 7, pp. 1945-1954, DOI: 10.1007/s12205-014-0240-9.

Tsai, M. K. (2014[2]). "Automatically determining accidental falls in field surveying: A case study of integrating accelerometer determination and image recognition." *Safety Science*, Vol. 66, pp. 19-26, DOI: 10.1016/j.ssci.2014.01.012.

Yu, Y. H., Yeh, C. H., Lee, T. T., Chen, P. Y., and Shiau, Y. H. (2014). "Chip-based real-time gesture tracking for construction robot's guidance." In: *ISARC Proceedings of the International Symposium on Automation and Robotics in Construction*, pp. 1-8, Australia.

Zhang, S., Teizer, J., Lee, J. K., Eastman, C. M., and Venugopal, M. (2013). "Building Information Modeling (BIM) and safety: Automatic safety checking of construction models and schedules." *Automation in Construction*, Vol. 29, pp. 183-195, DOI: 10.1016/j.autcon.2012.05.006.

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