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A CONCEPTUAL FRAMEWORK FOR IDENTIFYING CONSTRUCTION ACTIVITY INTENSITY IN HARSH WEATHER CONDITIONS

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Harsh Weather Conditions (HWC) are environmental hazards that directly affect construction worker's health and safety, with a corresponding negative impact on their productivity. Climate predictions predict worsening scenarios of hot and humid weather conditions extending into regions not previously subject to HWC. The predictions pose a significant potential risk and elements of current practices in the construction industry seriously compromise workers' safety and productivity. HWC have been shown to have impacts on individuals and influence working environments which taken together lead to inhibiting the achievement of practical, safe and productive practices. This research aims to highlight the need to automatically identify the construction activity intensity in HWC, with proposing a conceptual framework of computerized vision analysis (CVA) system. This framework includes construction activity matrices that classify steel, formwork, and concreate work into macro and micro movements, with including the engaged materials, tools, and equipment. This system is expected to help in measuring the impacts of HWC on construction workers' safety and its implications on their productivity by identifying the activity intensity level and worker's idle time at the crew levels.

Keywords: HWC, CVA, Safety, Productivity.

1 BACKGROUND

The construction projects include various types of the activities that are conducted in heavy intensive work and many risk factors can affect the delivery of the projects such as management and finical related factors, site conditions, worker's accidents and injuries, poor worker's productivity, weather conditions. The workers are the key success factors of the construction activities as most of the construction work depends on their physical effort. The environmental factors such as hot and humid weather conditions have been found to be one of the most influential factors in the construction work environment that influence the workers' safety and negatively impact their productivity. Thus, this research will try to improve the worker's safety with respect the effects of the hot and humid weather conditions that can positively improve their productivity and consequently the delivery of the construction projects.

1.1 Heat-Related Injuries and Fatalities

Eighty nine fatal injuries caused by the impact of HWC were recorded in the construction industry between 2011–2016 in the United States (U.S. Bureau of Labor Statistics 2016). In Japan, yearly average heat-related deaths between 1991 and 2001 was around 14 workers and 194 heat cases of absenteeism were reported in 2001 (Inaba and Mirbod 2007), which increased dramatically and reached 47 deaths in 2010 (Yi *et al.* 2016). In Hong Kong, the statistics for 2007-2011 reported 32 injures and 11 deaths that were caused by heat stress (Li *et al.* 2016), and in 2012, there were 28% of workers who experienced heat stroke symptoms (Yi *et al.* 2016). Between 1900–2011, general statistical records in Australia showed 55% of the natural-related factors fatalities were due to the effects of HWC (Zander *et al.* 2015). Between 1844-2010, it was also estimated the fatalities in Australia due to effects of HWC by 5332 deaths (Coates *et al.* 2014). The Office of Industrial Relations in Queensland (personal communication, May 9, 2018) reported that between the period 2010 and 2017, 53 hear-related claims were recorded within the construction workers. Four claims were fatal or serious whereas 49 claims were identified as non-serious claims. Furthermore, according to the industry heat map index of the Queensland, construction industry and Construction workers have the highest heat-related harm index (3) in a scale from low harm (1) to high harm (3) (Worksafe Queensland 2017). These alarming statistics of heat-related illnesses and fatalities have been considered as driven to investigate the actual impact of hot and humid weather conditions on the construction worker safety.

1.2 Construction Worker's Productivity Under HWC

A combination of physically demanding work and HWC can disrupt workers' productivity and overall performance (Li *et al.* 2016) and this has been directly linked to workers' health and safety (H&S) (Choudhry 2017, Shirali *et al.* 2016, Cheng *et al.* 2012). The effects of hot and humid weather conditions have extended to workers' productivity. For instance, construction organizations have faced challenges in dealing with workers' productivity losses due to hot and humid weather conditions, which have been found to be the main reason for 64% of the variation in productivity levels (Koehn and Brown 1985). Local indications in Australia have shown significant losses in workers' productivity due to HWC (Zander *et al.* 2015, Srinavin and Mohamed 2003). In Queensland, hot and humid weather conditions have been found to be the most influential factors on workers productivity (Conor and Panuwatwanich, 2013). This could explain the incurred productivity-related losses in this industry due to HWC, for example, Zander *et al.* (2015) estimated the worker productivity losses at $6.2 billion as a result of harsh weather in Australia during the period 2013–2014, the results of the Singh *et al.* (2013) study showed that Australian companies may lose one-third of their workers' productivity in HWC, Yi and Chan (2017) found that the crew productivity time is decreased by 0.33% when the Wet Bulb Globe Temperature (WBGT) increase by 1°C. Therefore, not only worker's safety but their productivity are both considered important in understanding to what extent the HWC influences the construction industry. Accordingly, it is important to apply an integrated approach including safety and productivity to assess the effects of HWC which can help to achieve aligned improvements in worker's safety and productivity (Choudhry 2017, Cheng *et al.* 2013, Miller and Bates 2007).

2 THE CONTEXT OF THIS RESEARCH

Previous studies in different regions in the world have investigated the problem of HWC in the construction industry by focusing on the individual factors of the construction workers that have manifested a wide range of variation (Yang and Chan 2017, Gatti *et al.* 2014), made generalization of the research outcomes difficult (Hunt 2011), and ignored the regional variations (Yang and Chan 2017, Tymvios *et al.* 2016, Dutta *et al.* 2015, Bates *et al.* 2009). Moreover, the literature has highlighted significant limitations in the applied methods of data collection (Rowlinson *et al.* 2014) in particular, that the intrusive sensing technology can hinder the workers' activities or create discomfort (e.g., sensors that weigh 1.5 kg; Wong *et al*. 2014, Chan *et al*. 2012), cannot persuade the employees and management in real-time monitoring, and require special physiological status monitoring (PSM) sensors and knowledge in physiology (Lee and Migliaccio 2016, Lee *et al.* 2015, Liang *et al.* 2011). There was also limited information about the applicability of such technologies including its associated costs and the social and culture influences of adopting continuous monitoring systems based on PSM (Gatti *et al.* 2013, Zhou *et al.* 2013). It is, therefore, imperative that research methods use sophisticated measuring devices and monitoring systems that have small and practical designs (Gatti *et al.* 2013, Russell-Smith and Lepech 2011, Miller and Bates 2007, Abdelhamid and Everett 2002).

Hence, the research problem that will be addressed in this study is that the existing research raises the question that how the effects of HWC can be measured in the construction site with non-intrusive and real-time measurements to enhance a proactive decision making that ensure safe work without compromising worker's productivity. There is also a lack of research to automate work-related factors, in particular, activity intensity under HWC, especially in Queensland.

3 THE RESEARCH AIM AND QUESTIONS

The aim of this research is to investigate the extent to which HWC impact on construction workers' safety and how HWC may influence crews' productivity levels while considering the influence of activity intensity levels of a limited range of activities at the crew level. This study proposes to use a quantitative approach involving real-time measurements of environmental conditions and automated activity intensity identification with crews' idle time and the utilization of computerized vision analysis (CVA). Real data synchronization will be employed as an input to a proactive framework that supports the site management with safe and productive decisions. To achieve the stated aim, this research addresses the following main questions:

- What is the potential applicability of an automated activity intensity identification system under HWC?
- To what extent do the various types of construction activity intensities impact on workers' safety?
- What is the potential application of CVA technology in supporting proactive decisions to maintain both safety and productivity under HWC?

4 RESEARCH METHOD

The measurements of HWC impacts on construction workers ideally depend on collecting information of the individual factors of the workers such HR, BR, and oxygen uptake level. Previous research has extensively employed this type of information in estimating the activity intensity levels which have been linked to the weather measurements such as degree of temperature, humidity and WBGT. However, the literature suggests that such measurements to be impractical when considering the real site applications due to intrusiveness of the PSM sensors; a wide range of variations in the collected information due to the effects of the worker's individual factors; and the time-, cost- and effort-consuming method of attaching sensors to the body of each site worker in different working shifts. Therefore, this research proposes a framework of AII under HWC to achieve a non-intrusive system for monitoring the worker's safety and productivity under HWC. This framework is expected to measure the worker's activities (activity, typical movements, engaged materials, tools, equipment and workstation), their idle time and weather parameters (degree of temperature, humidity and WBGT) in a real-time manner. This approach will employ the CVA technology of real-time video records to measure worker's activities. Thus, the system needs to collect real-time data from the video records and a local weather station.

4.1 Research Design

The research literature review included the understanding of the impacts of the HWC and the nature of the targeted construction activities. Based on that the research problem and aim have been formulated. To achieve the research aim, the research method will include three phases: (1) phase one, activity intensity matrix and CVA system preparation; (2) phase two will be designated to conduct a pilot measurement; and (3) phase three includes site measurements.

4.1.1 *Framework development*

This research proposes to develop an automated AII under HWC. This framework will enable the understanding and the identification of the nature of the construction activities, their associated intensities and the links between worker's safety and idle time under HWC. This framework can help to facilitate proactive decision-making for both safety and productivity under HWC. The AII formwork will be built on the concept of providing a massive amount of valuable information of the worker activities in non-intrusive and real-time manner. Thus, the data acquisition component of this framework will include the application of 2D sit cameras. The second component of the framework will include two layers of quantitative data analysis: (1) CVA application; and (2) data synchronization, activity intensity identification, WBGT thresholds and worker's idle time optimization. The last component of the framework will report the data analysis results to the decision makers via summarized detailed information of the worker's activity intensity levels compared to the WBGT thresholds and optimized idle time, as Figure 1 shows.

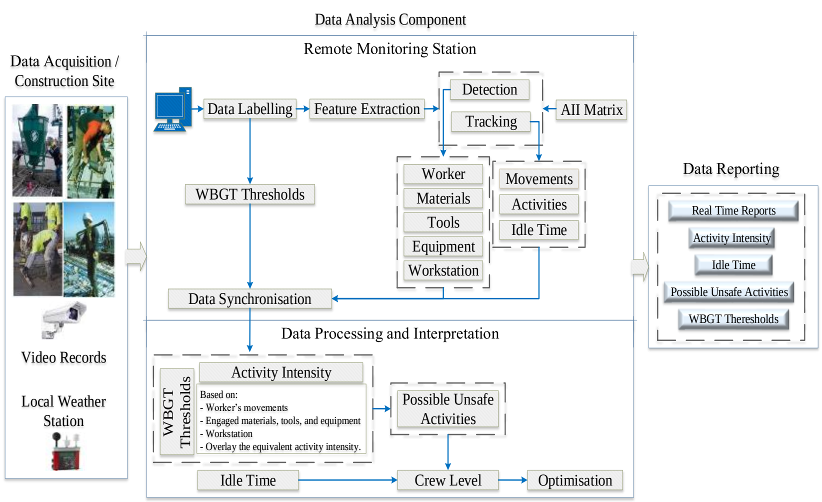

Figure 1. The proposed conceptual framework of AII under HWC.

5 CONCLUSIONS AND RECOMMENDATIONS

Literature review shows that construction projects are seriously encountered loss in workers due to injuries and fatalities as well as the increase of their idle time under HWC. The current state of the art related to HWC generally applied intrusive sensors to measure the effects of HWC and extensively emphasized on the individual factors of the works. However, the debate as to what the characteristics of the performed manual tasks and work-related factors that can help to improve safe work environment under HWC, becomes a pertinent question. Therefore, the aim of this research is to investigate the extent to which HWC impact on construction workers' safety and how HWC may influence crews' productivity levels while considering the influences of activity intensity levels of a limited range of activities at the crew level. This research proposes to develop an automated AII framework to achieve non-intrusiveness in site measurements under HWC. This framework is expected to develop an automated, non-invasive monitoring system that provides supports real-time data collection.

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