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PRACTICAL VALIDATION MEASUREMENTS OF A PHYSIOLOGICAL STATUS MONITORING SENSOR IN REAL CONSTRUCTION ACTIVITIES

AMMAR S.M. MOOHIALDIN[1], BAMBANG T. SUHARIADI[2], and MOHSIN K. SIDDIQUI[3]

[1]*Science and Engineering Faculty, Queensland University of Technology, Brisbane, Australia*
[2]*Dept of Construction Engineering and Management, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia*
[3]*College of Engineering, Qatar University, Al-Doha, Qatar*

The construction industry is one of the most hazardous industry and construction worker's health and safety in hot and humid weather conditions become a topic of a great interest for researchers and practitioners. Various physiological monitoring sensors have been employed to measure the physiological impacts of such weather conditions. However, the ability of these sensors to deal with the dynamic nature of the construction industry still under controversial arguments and there is a need to justify their applicability in real working conditions. This paper aims to investigate the accuracy of an off-the-shelf physiological monitoring sensor (Zephyr BioHarnessTM 3) in a real working environment when considering the impact of hot and humid weather conditions. Fifteen different construction workers participated in three site measurements, with monitoring two physiological parameters heart rate (HR) and breathing rate (BR). A non-parametric statistical test (Mann-Whitney) was applied to identify whether there is a significant difference between the medians of live data in the remote monitoring station and saved data of the sensor internal memories. The results showed that there are significant differences between live data and saved data. These differences were highly noticed in the third site measurements, as it included working in confined areas and trenches. The accuracy of live data is highly affected by types of activities and appropriate positions of the wireless connection devices (ECHO gate and repeater).

Keywords: Zephyr BioHarnessTM 3, Health and safety related on-site data collection, Heart rate, Breathing rate.

1 BACKGROUND

There are several technologies can be used for Physiological Status Monitoring (PSM) purposes. According to Alam and Ben Hamida (2014), there are 41 different wearable sensors available in the market for medical applications, 77 for fitness applications, 117 for lifestyle monitoring and 26 for entertainment.

"Zephyr" (Annapolis, Maryland, USA) is a leading global provider of healthcare products, and it is recognized innovator in patient monitoring and respiratory care devices. This technology is directed toward physiological status monitoring in training applications and in high-stress environmental conditions. In addition, it was successfully applied in some studies that are cooperated with Fire Department, NASA Ames Research Centre, National Guard Civil Support

Teams, and multiple US Special Forces contracts. Most of these studies supported and validated the application of Zephyr™ technology under extreme operating environmental conditions (Zephyranywhere (About Zephyr) 2015). The main tool applied for PSM is BioHarness™ 3, which is available in different forms based on the way of contact with the human body (compression shirt, chest strap, and holder). In addition, there are another tools are provided by Zephyr™ such as HxM™ BT, which mostly used for fitness monitoring. Zephyr website addressed several applications of their technology in various disciplines, such as sports, medical and other applications in addition to some published journals.

Different studies addressed the PSM applications by using Zephyr technology for different purposes, however few of them demonstrate the applicability, reliability, and accuracy of this technology in a real construction environment. Zephyr technology was recommended in several studies as a valid tool for PSM of construction workers. To illustrate, Gatti *et al.* (2011) assessed the reliability and accuracy of collected data of HR and acceleration by Zephyr technology during recording dynamic activities of construction workers. They concluded that Zephyr technology is a recommended technology for construction safety applications. A further application for Zephyr technology ("BioHarness BT") was addressed by Gatti *et al.* (2012a) for monitoring HR of construction workers in a lab-setting experiment, to identify physical strain level based on HR recorded data. Based on the result of Gatti *et al.* (2012b), Zephyr technology is considered as an effective technology for monitoring health and safety conditions of workers in the construction industry. It accurately and effectively measures HR in a dynamic nature of their tasks as well as their environmental conditions, without any interruption or hindrances. Furthermore, Migliaccio *et al.* (2012) were able to assess the physiological and ergonomic status of bending activities of construction workers where the authors incorporated the UWB PSM recorded data of construction workers by using Zephyr sensors. The authors concluded that Zephyr technology is a reliable tool for monitoring construction activities remotely. This conclusion was also supported by Cheng *et al.* (2013a and 2013b).

In another study, Gatti *et al.* (2014a) utilized Zephyr technology in construction physical strain assessment. They recommended HR, relative HR, and BR as effective measures for physical strain. Furthermore, Gatti *et al.* (2014b) validated Zephyr technology (BioHarness BT 1) as an effective tool for monitoring the physiological and ergonomic status of construction workers in both static and dynamic activities. The authors argued that Zephyr technology provides valid records for physiological status (HR) in both dynamic and static activities.

Another field of Zephyr technology application in the construction industry was addressed in Lee and Migliaccio (2014) study, where the authors utilized Zephyr BioHarness™ 3 in assessing the impact of hard weather conditions on construction workers' health and physiological conditions. Recently, Lee *et al.* (2015) addressed that, Zephyr BioHarness™ 3 chest belt is the most accurate and applicable tool for monitoring physiological status of construction workers while they are performing their tasks without any interruption or inconvenience. It is an important characteristic for effective PSM tools to contain a warning system for detecting vital signs of the subjects under study (Buller and Karis, 2007). This character is available in Zephyr BioHarness™ 3 technology, where it gives warning signs through producing different warning sounds and lights.

A further investigation in PSM technology was addressed in Gatti *et al.* (2012b) study such that the authors evaluated three different technologies for PSM applications "Zephyr BioHarness (BH), Zephyr HxM, and Hidalgo EQ-01". These technologies have different dimensions, weights, data transaction methods and measured variables. The result of Gatti *et al.* (2012b) comparison reveals to that, BH and EQ-01 technology provide reliable and effective tools for monitoring physiological status through measuring HR and BR of construction workers without

any interruptions to their tasks. The most important factor for getting a successful application of PSM technology are size, applicability, and reliability of the utilized sensors, and it should not hinder or interrupt workers performing the required tasks and activities. Another important issue is that, there is not any study addressed the application of PSM technology in Saudi construction market, and only one study was conducted in Arabian Gulf Region (UAE) using "Polar S720i" sensors.

Therefore, there is a higher need to investigate the argument that, Zephyr technology provides accurate, reliable and valid real-time records for construction workers while they are performing their normal tasks, without creating any interruption or discomfort especially under extremely hot and humid weather conditions in Saudi Arabia.

2 RESEARCH METHOD

Real construction site measurements were held in three different construction sites in Dhahran, Saudi Arabia. The participation was totally voluntary, and the participants were divided into groups according to their job, working shift, the day of recording. There was not any interruption to the participants' activities such that their physiological status was recorded simultaneously with passing time by using Zephyr technology. The two different sit measurements were conducted in the first construction in which steel structure installation and filter preparation for an AC station. The third site measurements included two different activities (shoveling and formwork) in order to prepare foundations for a parking building. All measurements were conducted under extremely hot and humid weather condition such that the highest degree temperature and relative humidity in the first and second site measurements are 48°C/19% and 47°C/20%, respectively. These measurements were conducted during morning shifts with considering three different sessions (outdoors measurements, indoors measurements, and resting measurements). Third measurements were conducted during night shifts where relative humidity was higher than the morning shifts. The highest degree and relative humidity in the third site measurements are 33°C and 40%, respectively. In each measurement, five participants and five sensors were employed in the measurements, which means fifteen participants in all measurements.

Zephyr sensors are able to provide wide options of physiological status reports, which will be employed in this study, to test the proposed hypothesis. Zephyr sensors can provide hourly records for different parameters and vital signs. In this study, only HR and BR recorded, and live data will be tested. Zephyr BioHarness technology provides two different types of software for monitoring the participants and providing warning signs in dangerous situations. The available software is OmniSense Analysis and OmniSense Live. The OmniSense Live assists continuous monitoring purposes and provides warning signs for all participants at the same time. The other software, OmniSense Analysis provides a graphical presentation of the monitored subjects and it supports analysis purposes.

Zephyr BioHarnessTM 3 provides one ECHO gate and one ECHO repeater to be used in the conducted measurements. Each one is able to cover up to 300 yards range i.e. 600 yards totally. Therefore, participants should be within this range and ECHO repeater should be placed in 300 yards far from ECHO Gateway.

After each recording session, the participants were asked to answer the following questions based on their feeling and perception:

- Is wearing BioHarness Belt makes you perform your activities without any discomfort?
- Do you prefer that this belt was designed to be worn on wrist or shoulder?

3 DATA ANALYSIS

The results of the proposed two questions show that one of the participants declared that wearing Zephyr belts create any discomfort. Nine of participants preferred Zephyr belts to be manufactured in such way that it possible to worn in wrist or shoulder and only six of them did not.

Zephyr sensors are wireless sensor has the ability to monitor physical remotely. The wireless connection ECHO Gate covers a circle of 300-yards diameter circle. The repeater also covers a circle of 300-yards diameter circle which means Zephyr system can cover 600-yards totally. Based on this, the participants in construction site measurements moves within this range. However, the signal of the Zephyr sensors was missed several times during recording sessions. The sensors have the ability to keep the records in an internal memory in addition to the live records that are sent to the software simultaneously. It is important to identify whether there is a significant difference between the live recorded data (HR and BR) and the data that is saved in the internal memory of Zephyr sensors. In this research, Mann-Whitney test is applied to identify these differences with considering significant level $\alpha = 0.05$. The proposed null and alternatives hypothesis are:

- H_0: There is not a significant difference among the medians of live and saved records of both HR and BR.
- H_1: There is a significant difference among the medians of live and saved records of both HR and BR.

The results of the proposed tests are summarized in Table 1. Mann-Whitney test results shown in Table 1 indicate to some differences between live and recorded data. In the first construction site measurements, only two significant differences were identified in HR data and one significant difference was identified in BR data. The second construction site measurements included three significant differences in HR data and two in BR data where in the third construction site measurements included the highest number of significant differences in HR and BR data, which are four significant differences in both categories.

Table 1. Results of Mann-Whitney test for recorded and live data comparison.

Subject	HR/BR	1st Measurement		2nd Measurement		3rd Measurement	
		P-Value	Decision	P-Value	Decision	P-Value	Decision
1	HR	0.000	Significant	0.000	Significant	0.0337	Significant
	BR	0.000	Significant	0.000	Significant	0.000	Significant
2	HR	0.000	Significant	0.3894	Insignificant	0.000	Significant
	BR	1.000	Insignificant	0.5581	Insignificant	0.9856	Insignificant
3	HR	0.0931	Insignificant	0.0053	Significant	0.000	Significant
	BR	0.6886	Insignificant	0.9409	Insignificant	0.000	Significant
4	HR	0.0545	Insignificant	0.000	Significant	0.000	Significant
	BR	0.4283	Insignificant	0.000	Significant	0.000	Significant
5	HR	0.7878	Insignificant	0.4991	Insignificant	1.000	Insignificant
	BR	0.3744	Insignificant	0.8093	Insignificant	0.000	Significant

4 RESULTS AND DISCUSSION

The results of the proposed paper show that Zephyr BioHarness Belts are suitable to be used in construction industry to monitor construction workers' physiological status remotely under extremely hot and humid weather condition. Zephyr BioHarness Belts do not create any discomfort or interrupt the workers' activities. In addition, most of the participants preferred that Zephyr belts to be manufactured in such way that it possible to be worn in wrist or shoulder rather than chest belts.

The results of the Mann-Whitney test show that there are significant differences between recorded and live HR and BR data. However, the estimated differences between the recorded data and live data do not exceed the value of one in both HR and BR in the first and second measurements which is a good indication to a good level of accuracy in the recorded and live data of HR and BR. On the other hand, the maximum differences between the recorded and live BR data reach to the value of eight in the third measurements. In addition, these differences were not so much effective especially in the first and second site measurements. In these measurements, the construction site under study did not include any confounded areas or working in trenches. In the third measurements the location under study included working in trenches, which may create problems in the wireless connection.

5 CONCLUSIONS AND RECOMMENDATIONS

Different innovative technologies have been successfully applied to support construction workers' health and safety. However, there was not any research that addressed validity test of these technologies in Saudi construction market. This paper is aiming to investigate the accuracy of the recorded data that is provided by Zephyr BioHarnessTM 3 sensors with considering extremely hot and humid weather conditions in Saudi Arabia. Three different construction site measurements were conducted in order to test the proposed hypothesis. Two of these measurements were taking place on the same construction site where the third one was conducted in different site measurements. The results of the proposed paper show that Zephyr BioHarness Belts are suitable to be used in construction industry to monitor construction workers' physiological status remotely under extremely hot and humid weather condition. It is preferable to redesign Zephyr belts in such way that it possible to be worn in wrist or shoulder rather than chest belts. The accuracy of the recorded data is highly affected by the construction site such that the results show some significant differences between recorded and live data in the third site measurements. In these measurements, construction workers performed their tasks in trenches, which may create problems in the wireless connection. Zephyr technology is recommended to be applied in construction safety and productivity applications. In order to improve wireless connection, it is recommended to select appropriate positions for the ECHO gate and one ECHO repeater in the construction site.

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