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Vancouver, Canada

May 31 – June 3, 2017/ *Mai 31 – Juin 3, 2017*

CONSTRUCTION SAFETY PERCEPTION ANALYSIS USING AFFECTING SENSING TECHNOLOGY AND VIRTUAL REALITY

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ABSTRACT

Virtual Reality (VR) is widely used in conception, planning and design phases of a project, mainly for communication and collaboration. During the construction phase, safety demands major attention at any active construction site. Iterating among alternative safety plans in real world conditions can be dangerous, expensive, resource intensive and often not feasible. Safety is not only governed by what regulations are at place; the perception of the workers towards site safety conditions is also equally important. In other words, in addition to imposing safety rules, it is also equally important that the workers feel safe in their working environment. This paper explores the potential of leveraging VR to investigate on perceptual response of workers on site safety conditions. A VR environment is created based on real-time geometric (laser scan) and location (GPS) data collected from moving equipment and workers at an active construction site. Hazards are introduced into the VR scenes in a systematic and controlled manner. Subjects are exposed to the scenes through a head-mounted VR system. The experience of the subjects in different hazardous scenarios are recorded through Affective Sensing devices and a questionnaire. Affective sensing technology can track human physiological responses in real-time. The goal of this research is to leverage VR environment to (i) test the feasibility of using affective sensing devices for tracking human responses to hazardous situations, (ii) study the potential of exposing construction workers to virtual hazards for training purposes. The results from this study will give a better understanding of potential of VR in construction safety training and management.

Keywords: - Construction Safety Perception, Virtual Reality, Affective Sensing, Galvanic Skin Response

1. INTRODUCTION

Construction industry is one of the most hazardous industry and has consistently suffered the most number of occupational fatalities over many years (Pradhananga, 2014). Research in construction safety has focussed on identifying the reasons of previous accidents by statistical analysis of injury data, manual observations on jobsites and real-time data tracking technologies. The results of such researches are usually strategies for enhancing safety on the site. New regulations, programs or policies are enforced in place as a way to prevent accidents. But, these safety programs are not enough without enhancing workers' ability of proper hazard awareness and recognition (Chen et. al., 2013). The ability of the workers to perceive the hazards and react appropriately can significantly impact the chances of accidents and injuries. Workers' personal traits and individual characteristics can be classified as human factors. Human factors have primarily been studied qualitatively. Qualitative methods tend to generalize the results to entire workforce. However, human perception differs from person to person. This implies that studying human factors like their ability to handle extraordinary situations or, in a construction scenario, emotional changes that a worker goes through when exposed to an unexpected situation on site, can play a vital role in uncovering latent reasons behind construction accidents.

Literature shows that stress or emotional changes resulted from danger or unexpected changes induce degradation of perceptual-motor performance, amount of focus on peripheral information and tasks decreases (Staal, 2004). Study of emotional and physiological status of the workers can provide a lead on future potential hazards and help in taking preventive measures to avoid accidents. This paper tests the feasibility of using affective sensing technology to improve understanding of the safety situation of the site and incorporate the workers' perspective into safety analysis. It uses virtual reality environment for the experiment with a motive to test feasibility of using virtual reality in construction safety training. Virtual reality provides a platform to simulate hazardous situations in the safety of lab and does not require the participants to be exposed to actual hazards on site. Virtual reality is also effective for training and experimentation because it provides a platform to design and replicate desired scenario multiple times for participants. In actual site, every scenario is unique and cannot be exactly replicated.

2. BACKGROUND

2.1 Leading Indicators of Safety

The safety statistics and injury reports produced after an incident at a construction site has been termed as lagging indicators of safety (Pradhananga, 2014). They fail to provide an insight on what might happen at the site but merely provide an after-the-fact report of what has happened on the site. To overcome this limitation, leading indicators of safety have been introduced. These indicators help in predicting hazardous situations and undesired events. (Grabowski et al., 2007) Leading indicators also have the ability to assess whether hazard is under control and identify the causes on an incident (Lindsay, 1992). Leading indicators might be beneficial for effective plan modifications to decrease severity of the incidents (Hinze et al., 2013). Examples of leading indicators of safety can be near misses and at-risk behavior. Near miss events are the events that had a potential to cause injury or other type of damages but did not occur in reality (Marks, 2014). At-risk behavior can be explained as the worker' behavior that has potential to result in hazardous circumstances for a worker or equipment operator in the field (Pradhananga, 2014). This study focus more on the at-risk behaviors. Understanding what makes workers or equipment operators stressed, tensed or distracted in the field, what factors bring about lack of concentration and incorrect decisions, what aspects need more attention and what bring about at-risk behaviors.

2.2 Non-intrusive Affective Sensing for tracking workers' behavior

Physical characteristics are those characteristics that can be observed without any kind of equipment or tools, just by observing people; while, physiological characteristics are the ones that require tools or sensors for measurement. **Error! Reference source not found.** shows physical and physiological characteristics or measures that can be leveraged to track human reactions to examine stress (Sharma and Gedeon, 2012).

Figure 1: Common physical and physiological measures and their usual sources for the measures (adapted and modified from Sharma and Gedeon, 2012).

Most widely studied human reactions pertain to stress. The impact of the stress on regular activities is widely accepted and effects on immune and cardiovascular systems. If stress becomes chronic, it makes individuals more susceptible to illnesses and infections (Segerstrom & Miller, 2004). Accordingly the age, gender, experience and similar effects individual’s reaction to the stress may vary. Symptoms of stress can be categorized as hormonal imbalances, physiological (Hugdahl, 1995) and physical changes like, behaviour and gesture (Sharma & Gedeon, 2012), facial expression (Sharma & Gedeon, 2012) and eye reactions (Liao et al., 2005; Partala & Surakka, 2003). Under stress increase in hormones can be detected by invasive methods like blood, saliva or urine samples; on the other hand, heart rate (HR), blood pressure (BP), pupil diameter (PD), galvanic skin response (GSR) can be measured with non-invasive technics to quantify the stress effect on human body (Sharma & Gedeon, 2012). This paper deals with non-invasive physiological status monitoring system for Non-invasive Affective Sensing (Zhai & Barreto, 2006) of workers’ reaction to construction environment. Non-invasive means there is no need of introducing medical instrument or drawing blood from the subjects and affective sensing pertains to study that deliberately influences emotions.

2.3 Virtual Reality in Construction Research

Virtual reality is an immersive visualization of real world objects and scenes which can be used in practice and education for architectures, engineers and contractor involved in design and construction phases. The importance and effectiveness of virtual reality comes from the sense of presence and scale makes feeling like observing a realistic world (Cheng & Teizer, 2013). Virtual reality methods can be grouped into two as desktop-VR and immersive-VR. While desktop-VR provides interaction through a computer monitor, immersive-VR provides a direct interaction with the virtual environment (Setareh et al., 2005). Total immersive-VR and Semi-immersive VR are the two different types for immersive-VR, for which total immersive-VR creates an environment that user is totally immersed in the virtual world while semi-immersive VR keeps some parts of the physical world in the field of view (Lu et al., 2001). The benefits of VR systems make them widely used in health industry (Sen et al., 2015; Luciano et al., 2009), sports (Stinson & Bowman, 2014; Pan, 2015) and manufacturing process (Seth et al., 2011) With the help of this technology work environment and workers’ safety behaviors can be improved by training and educating designers, planners and workers right from the front-end project phase. If real-time data is being used under potential incidents, data visualization can be used to have more effective rescue by engineers and managers. Additionally, all of these information can be documented and used for future safety practices and trainings (Cheng & Teizer, 2013). Virtual reality provides an active experience rather than a passive one and the person totally immersed in the environment is not distracted by external factors. It eases the process of analyzing and learning of complex subjects or designs. There is minimal risk in simulating hazardous conditions and exposing subjects to gaze their reaction. Safety training can be experienced in a more pleasing way with higher level of learning.

3. OBJECTIVES AND SCOPE

The main objectives of this research are to leverage VR environment to (i) test the feasibility of using affective sensing devices for tracking human responses to hazardous situations, (ii) study the potential of exposing construction workers to virtual hazards for training purposes. The research is limited to virtual environment and no experiment has been done in real construction site. The final goal is to test the potential of implementing the technology in the real site. The data collection is limited to student participants with knowledge about construction processes and safety regulations.

4. EXPERIMENT AND DATA COLLECTION

Figure 2 shows the basic workflow of the experiment, data collection and data analysis. The steps and components of the workflow are discussed in detail below.

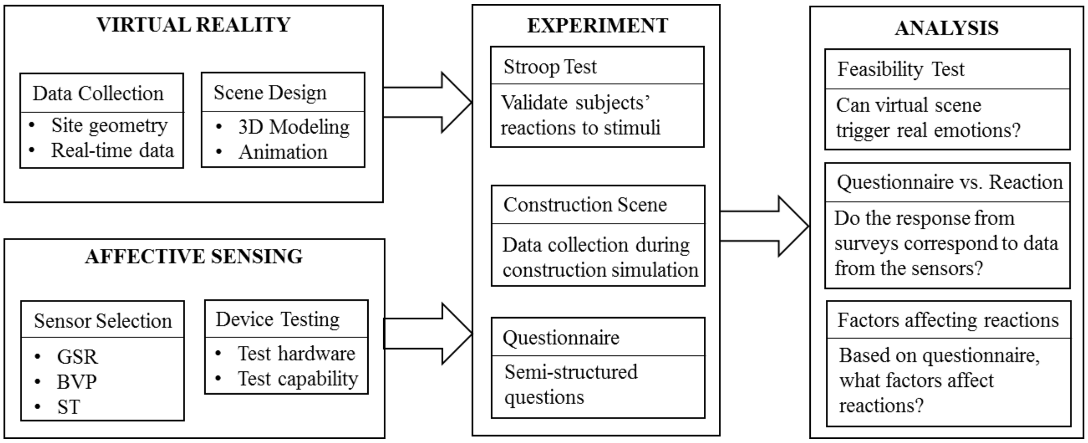
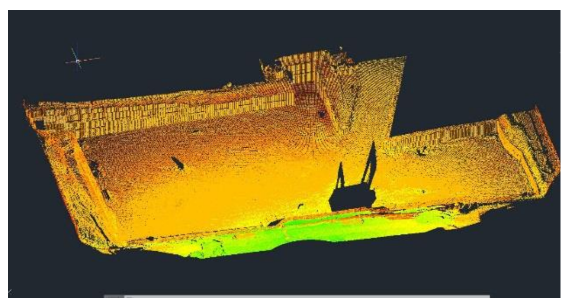


Figure 2: Workflow for the experiment and data collection

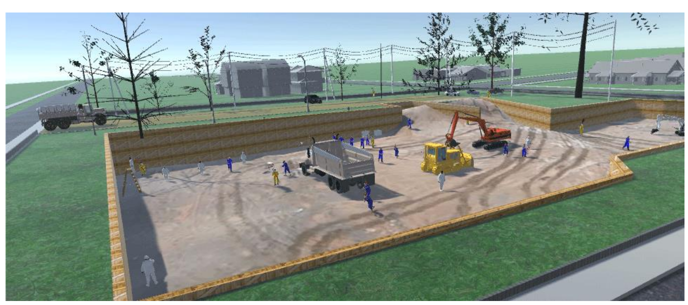
4.1 Data Collection and Scene Design

Data was collected during the excavation phase of the Engineered Biosystems Building (EBB) at Georgia Institute of Technology Campus at Atlanta, GA. The dimensions for site was approximately 120m x 100m. The excavation volume is 40,000 cubic yards and the period for excavation starts from November 28, 2012 and ends at February 18, 2013. Site geometry was recorded through multiple laser scans and all the mobile equipment and workers' movement were tracked with portable GPS devices (Pradhananga, 2014). A virtual reality model with appropriate simulations was developed in Unity 3D for the experiment. Figure 3 (a) shows a picture of the actual site, Figure 3 (b) shows the point cloud obtained from the laser scan on the site and Figure 3 (c) shows the VR model developed for the experiment.

(a) Picture of the real site



(b) Laser scan of the site



(c) Virtual Reality model of the site

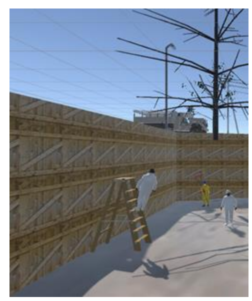
Figure 3: Real-time data-based VR Scene development process

The subjects were exposed to the VR environment through a head mounted Oculus headset. The subject would find themselves in the driver seat of a dump truck and the truck starts moving through the site without the subjects being able to control the movement. The subjects were, however, free to move their head around from the view point of the dump truck driver. Appropriate sounds were added to provide a more realistic feeling. The most common hazards on construction sites were identified to study subjects' responses in VR environment. The "Fatal Four" hazards - fall, struck by, caught in/between and electrocution were introduced to the scene on top of the actual activities happening at the site. Electrocution hazard was simulated with the help of a group of electric pole that tip over after sparkles appear on the poles (Figure 4 (a)). Caught in/between hazard is simulated with a cave-in scenario in which a worker tries to rescue himself from the earth caving in towards him (Figure 4 (b)). Struck-by was introduced by a worker passes by the truck (Figure 4 (c)) with the aim of giving a near miss incident experience (no clash between worker and truck). Finally, for fall hazard, simulation included a steel I-beam falling from crane into the middle of the scene and a worker loosing his/her balance and falling from the ladder while working besides a wall (Figure 4 (d)).

(a) Electrocution

(b)Caught in/between

(c) Struck-by



(d) Fall from a ladder

Figure 4: Fatal four hazards introduced into the scene

Total duration for the simulation was 370 seconds with all major four hazards. During simulation a truck completes the pre-designed route in construction field, at the same time all the designed incidents take place. With the help of the camera set inside the truck subjects follow the path like an equipment driver. The scene is designed into two phase to gradually increase the intensity of the stumuli. The first half (first 180 sec) had less distraction and incidents compared to the second half. The second half of the simulation contained more distractions, more hazard scenes and a lot number of workers and equipment to make our subjects more occupied. Figure 5 shows the timeline of the stumuli introduced in the developed construction simulation. More details about the data, developed environment and the experiment can be found in Ergun (2016).

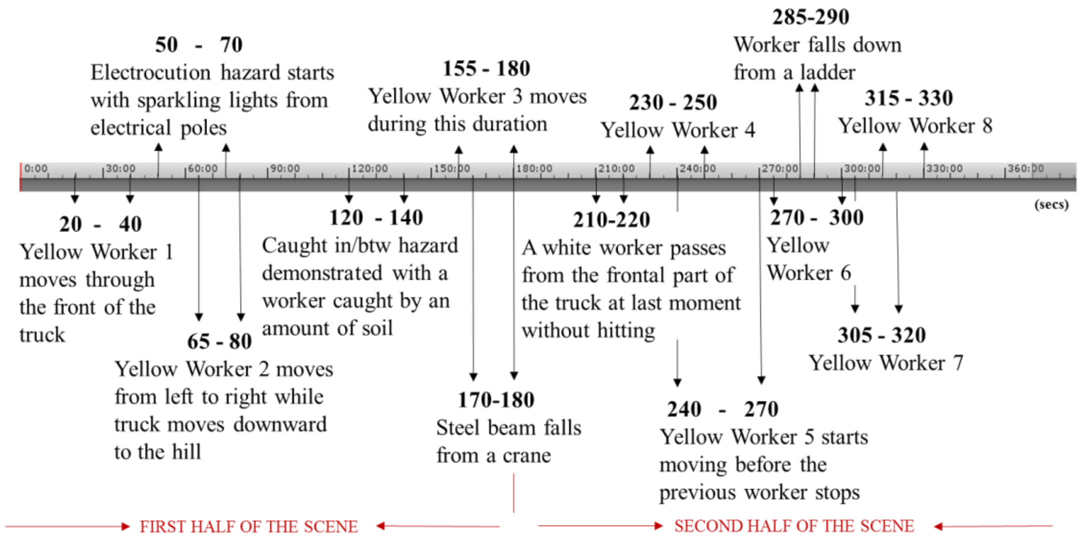


Figure 5: Timeline of stimuli in the developed construction simulation

4.2 Experiment and Data Collection

The experiment was conducted on 12 subjects majority of which consisted of graduate students have education and background in construction field with an average age of 25. The experiment was conducted in three steps as shown below. Neulog Galvanic Skin Response (GSR) devices were used to track the emotional changes or behavioral changes in the participants while conducting the experiment. A study by Sharma and Gedeon (2012) identified following order in terms of most effective technology for measuring stress in human body – 1) Heart Rate Variability (HRV), 2) Galvanic Skin Response (GSR), 3) Electroencephalography (EEG), 4) Pupil Diameter (PD), 5) Voice, 6) Eye Glaze, 7) Facial Expression, 8) Blood Pressure (BP), 9) Skin Temperature (ST), 10) Blood Volume Pulse (BVP), 11) Eye Blinks and 12) Respiration. Based on the ranking, GSR technology was selected considering the ease of use and effectiveness in measurement. GSR is based on electrodermal activity of human body that causes variation in electrical characteristics of the skin. The device can be worn on two fingers while the palm is in resting position. Zhai and Barreto (2006) provides a detailed information on GSR and its use in human affective sensing tracing.

<u>4.2.1 Stroop Test</u>

The Stroop test is a standard test usually used to measuring one's mental and cognitive capacity and requires cognitive processing throughout the performance (Nguyen et al., 2015). Stroop test was adapted for this research to assess if the subjects' reaction measured by the devices comply with standard and accepted Stroop test results before using the devices for the experiment. The Stroop Test developed for this research is a based on the model called as "Paced Stroop Test" designed by Zhai & Barreto (2006). The test basically presents the name of a color on the screen. The color of font might or might not be the same color as the name that appears. Five different and distinct colors were selected for the experiments. With this interactive Stroop Test method, subjects were asked to click on one of the five buttons (with name of the five selected colors) on the screen within 3 seconds of seeing the name of the color. If the subject did not give an answer, the system automatically moved to the next color. The test involved two parts named as "Congruent Segment" and "Incongruent Segment". The congruent segment presented the name of a color in the same font color as in Figure 6 (a). In incongruent segment, the name and the color of font did not necessarily match (Figure 6 (b)).The test consisted of 45 trials of congruent segment and 30 trials of incongruent segment. The purpose to design the Stroop Test is the tally our results with the standard test to assess the feasibility of using the technology for construction safety purpose.

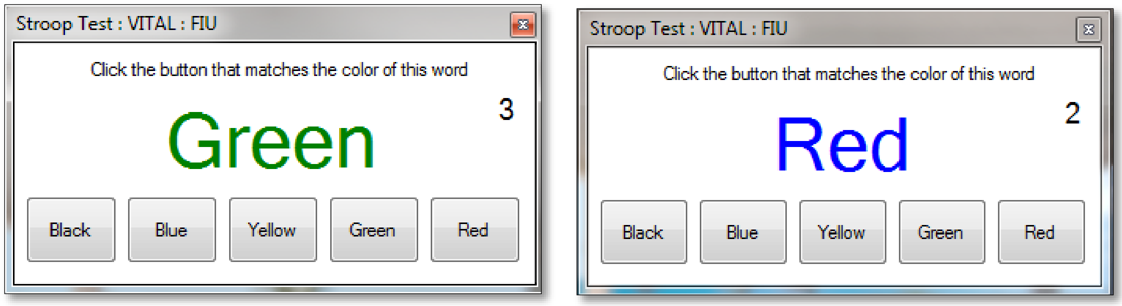


Figure 6: (a) Congruent Stroop Test, (b) Incongruent Stroop Test

4.2.2 Construction Simulation

Firstly, the subjects were briefed about the Institutional Review Board (IRB) protocols and about the expectations and their rights to quit the experiment at any time. Thereafter, they were equipped with the GSR sensors and were given some time to rest. The resting time depended upon how long their GSR reading took to stabilize. About a satisfactorily stable GSR state was reached, the subjects were asked to take the stroop test (discussed above). After the stroop test, a resting time is again given to the subjects to obtain the stable GSR value again.

After the subjects' GSR status returns back to stable state, the subjects are asked to wear the Oculus headset and the developed construction simulation was played. The subjects are also requested not to move their hand with the GSR device in the middle of the experiment as it might affect the readings. The experimental setup is shown in Figure 7. After the experiment, the subjects are asked to answer a set of questions discussed in the next section.

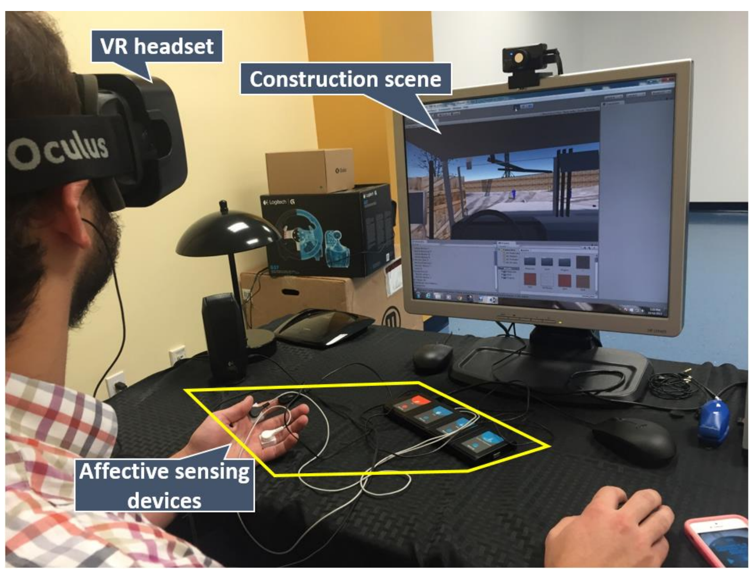


Figure 7: VR-based experiment using Affective Sensing Devices

4.2.3 Questionnaire

A semi-structured questionnaire survey was conducted at the end of the experiment to tally the reactions obtained from the subjects to their perception on how they performed. The purpose of the questionnaire is to cross check the physiological response of the subjects to their oral description of the experience. The other purpose of the questionnaire was also to identify the weaknesses and potential areas on improvement in the experimental setup based on the subjects' experience.

5. PRELIMINARY RESULTS

Figure 8 shows the variation in GSR values over time for all the subjects. Each line represents the GSR data pertaining to one subject in the experiment. Figure 8 also shows that the reactions can drastically change from person to person and the sensitivity or changes in reactions are also different in different subjects. The spikes denote the change in emotional states of the subjects. Each time there is an emotional change in the subject, a spike is generated. The figure shows that there were subjects who were very sensitive to the stimuli introduced in the scene while some subjects were pretty much indifferent to the stimuli. The gradual negative slope of the entire chart shows that the anxiety in the subjects because of being exposed to the new experimental scene gradually dies out as they progress through the experiment.

The preliminary observations show that emotional response of people are based on individual characteristics. It implies that different people will act differently in construction sites when exposed to same hazardous conditions, which is expectable. It also implies that these personal characteristics need to be understood to properly cater the training requirements to the workers for safer operations. Current practice is to provide the same instructional training material to all the workers irrespective of their behavioral and emotional state and requirements. Because of emergence of readily collectible real-time data, it might also be feasible to tailor a personalized training method for each worker by understanding their personal needs.

The results from the experiment need to be studied in detail and need to be tallied against standard stroop test and questionnaire survey from the subjects. Another aspect of the experiment was to test if virtual reality environment can be used as an alternative to actual site training. For this, the same experiment needs to be conducted at a real site and the data needs to be tallied with the data collected from the lab experiment.

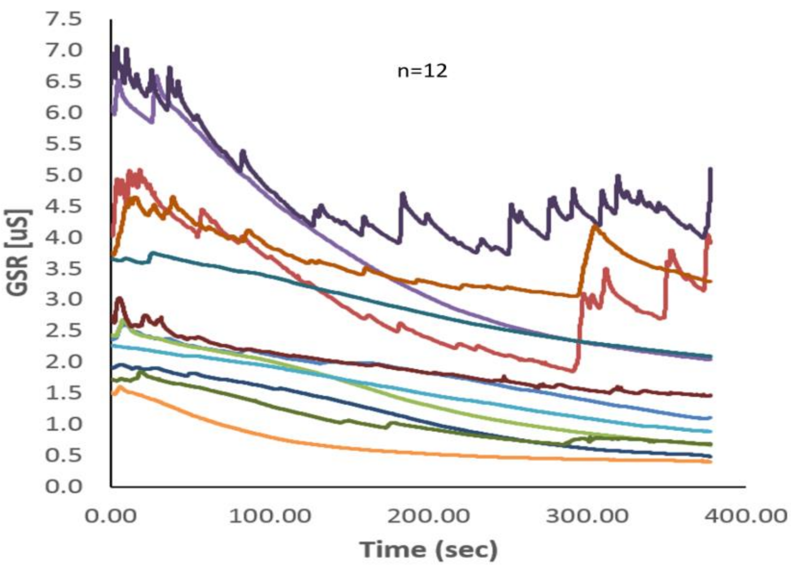


Figure 8: GSR value vs. Time

6. CONCLUSION AND FUTURE WORK

The purpose of the research is to test the feasibility and explore the future possibilities for leveraging affective sensing technology for safety related research and practice. From preliminary observations, several problems in using virtual reality for monitoring construction workers' physiological reactions were identified. Some of them are indifference to the VR environment, lack of control making the experience unrealistic, expectation of what might happen next in the VR scene, proximity and intensity of the hazards not enough to trigger a response, duration and magnitude of hazards and the experiment. There is a possibility that the physiological responses through different types of technologies and sensors may vary from subject to subject meaning that a subject's eye gaze might be a better indicator of his/her physiological status compared to GSR while another subject might be more reactive to GSR compared to eye gaze tracking. Experiments with more types of sensors can potentially validate this assumption. The incoherent responses from the subjects to the experiment indicate potential of further research after addressing the problems identified during this study. If found effective, the study has potential to be used in many other fields; like, driver trainings, productivity enhancement trainings and disaster response trainings.

The results can also not be generalized because all the subjects were students and actual construction workers were not included. Since the target for the research is construction workers, an experiment with real workers might yield more valuable results. Perspective of workers' about real site conditions and existing safety precautions or regulations and workers' opinions might contribute in enhancing the experience and the experiment. The data collection was also done in lab environment so the responses need to be validated in real construction site to justify the use of affective sensing technologies.

Hence, the paper presented a preliminary experiment to explore the potential of leveraging affective sensing and virtual reality for construction safety purposes. The preliminary observations indicate that more experiments need to be conducted to validate the claim. The results also implied that personal factors do matter while studying how different workers respond to unexpected situations in a jobsite. Research along this line may pave a new avenue of research towards real-data data oriented safety analysis methods that incorporate crucial human factors in the analysis.

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