

Virtual Reality-based Personalized Learning Environment for Repetitive Labor-intensive Construction Tasks

Sudip Subedi, Nipesh Pradhananga, Armando Carrasquillo, Francisco Lopez
Florida International University
Miami, Florida

In recent years, several developments have been made towards improving construction methodology and equipment used to facilitate better construction environment and create safer working sites. Yet there always remain repetitive construction tasks demanding heavy physical performance from the laborers, seemingly safe at the time of performance but eventually causing musculoskeletal disorders. This research explores an approach to monitor the postural behavior of a subject during a lifting operation and provide personalized feedback to the subject to encourage ergonomically safe lifting technique. Posture was measured by tracking subjects with a Kinect camera. The joints were extracted from the skeleton and ergonomic analysis was performed on the extracted lift data. Occupational safety and health administration (OSHA) offers a guideline for safe lifts but does not provide a quantitative technique of analysis. This method also puts effort to device a way to quantify such guidelines for a given scenario. The main and final goal of this study is to leverage virtual reality as a personalized learning environment in which the subjects can interactively learn about safety from their own data as well as their peers.

Key words: Construction Safety, Personalized Learning, Real-time Tracking, Ergonomics

Introduction

Construction industry plays the major role in the economic development of every nation. With the increasing urbanization and industrialization, the need of construction industry is also rising. In the past few years, there has been major improvements in construction field including the advancement in the construction methodology, mobilized equipment and laborers' health and safety (Koningsveld and Van der Molen 1997). Zero injuries and fatalities at the construction site has always been the goal at any construction site, yet, construction suffers the highest number of fatalities among all industries. Several researches have been conducted supporting the well-established fact that the health and safety of the laborers involved in the construction site directly affects the productivity as well the profitability of the project. But still, there are various construction hazards (both fatal and non-fatal) that the laborers are suffering from. As per the 2014 report from Bureau of Labor Statistics US Department of Labor published on December, 2015, the rate of injury and illness per 100 full-time laborers in construction is 3.6 (BLS 2016).

The increase in the use of mechanical equipment in construction has significantly reduced the laborers based physical works as well as the hazards associated. Still the laborers are subjected to the construction activities requiring repeated heavy lifting and unsafe work postures for a longer duration (Hartmann and Fleischer 2005; Schneider and Susi 1994). Several researches have shown that the repetitive exposure to the working environment demanding heavy lifting and unsafe work postures might result in the musculoskeletal disorders, decrease in productivity and profitability (Cheng et al., 2013). As per the National Institute for Occupational Safety and Health (NIOSH), musculoskeletal disorders (MSDs) are soft-tissue injuries caused by sudden or sustained exposure to repetitive motion, force, vibration and awkward positions. Massive construction operations involving heavy equipment gain attention in terms of research and optimization, also because of the immediate cost involved in such operations. But MSDs happen because of a slow exposure of laborers to unsafe or awkward positions over a long period. There is no apparent cost involved to such problem. Also, such unsafe behavior cannot be easily tracked through existing real-time tracking technologies. The laborers are also given instructions in groups which does not necessarily cater to their individual needs. In such situation, personalized tracking and feedback system can potentially assess and guide laborers to work safely. This paper proposes a method in which laborers' movement are tracked, their posture analyzed and personalized feedback is given in a virtual environment.

Real-time tracking for ergonomic analysis of labor-intensive tasks has recently gained attention due to exponential growth in tracking technologies. Besides vision-based techniques, physiological status monitoring devices have been used to track laborers' body posture to categorize lifting activity into safe and unsafe (Cheng et al., 2012). The laborers had to wear a strap around their chest for the device to track their body posture and other vital statistics. Kinect camera was used to avoid the laborers having to wear expensive devices (Ray and Teizer, 2012) to accomplish similar results. The studies focused on detecting safe/unsafe behavior but did not consider a personalized feedback system for the laborers.

Personalized learning and Virtual Reality have been listed as two among 14 grand challenges in engineering (NAE 2016). Personalized learning is an education or training tailored to meet different learning needs of learners. In construction domain, research on performance of each worker based on real-time location data was done by Pradhananga (2014) to minimize human-equipment interactions. Virtual reality has been used in construction education and training to boost confidence in laborers before they go to an actual site (Teizer et al., 2013). As well, the use of the depth sensor cameras to track the construction worker movements in real-time has been validated by many researchers (Cheng, Tao et al., 2013; Khosrowpour 2014; Rafibakhsh, Nima et al., 2012; and Li, C. and Lee, S., 2011).

This paper focuses on a method to track worker movements in real-time and provide them a personalized feedback in virtual reality to assist them in perceiving the areas of improvement while learning from their peers' performance.

Objective and Scope

The objective of this study is to design a method for (i) automatically identifying areas of improvement in laborers' performance in repetitive labor-intensive tasks, (ii) providing them with personalized feedback in interactive virtual reality environment. This study is limited to repetitive labor-intensive tasks and preliminary results presented in this paper pertains to a basic lifting operation. The paper only focuses on outlining the method and presenting a sample data collection activity. The paper does not present results pertaining to the actual data collection.

Methodology and Preliminary Results

The proposed method relies on an experimental process of data collection, analysis and visualization. The overall framework consists of following steps:

1) Data Collection

    a) Normal lifts

    b) OSHA recommended safe lifts for the same situation

2) Data and Activity Analysis

3) VR-based Personalized Feedback

The steps are detailed in context of a pilot experiment done to test the feasibility of the method and the technologies used for the experiment. The following section will explain the steps and provide a pictorial demonstration of the step.

1) Data Collection

Data is collected from laborers while they perform regular tasks. For ergonomic analysis, data pertaining to joints in the laborers' body needs to be tracked in real-time. For the pilot study, a Kinect camera was used to track the participants' movement in real-time at around 30 frames per second. Kinect camera can detect and track human skeleton which, in turn, can be used to analyze the posture for safety. Student participants were used for the experiment which was performed in a construction lab to simulate a construction site setting. Thirty lifts were performed by each participant for statistical analysis. Figure 1 shows the posture of a participant for good and bad lifts while performing the experiment. The results below only demonstrate the result obtained from one participant.

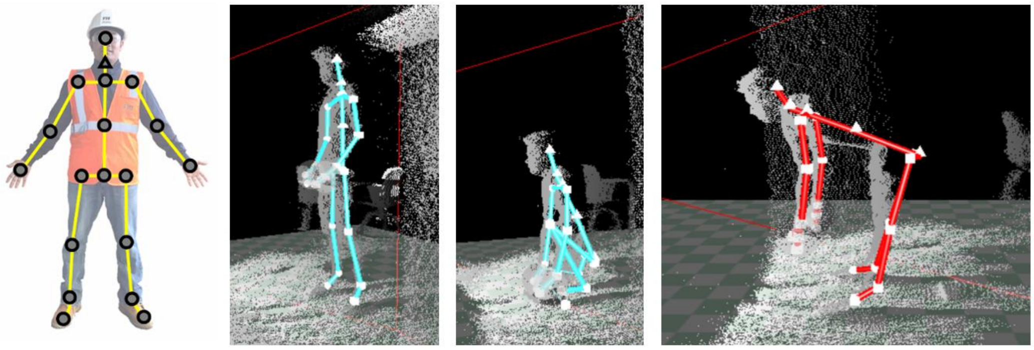

Fig. 1. (Left to right) Joints in human body, Joints detected by Kinect camera, Good lifting posture, Bad lifting posture in red

In addition, the participants were asked to wear the physiological status monitoring (PSM) device to keep record of postural data, heart rate, breathing rate and core temperature for reliable and rapid monitoring of physiological status. The participants wore the chest strap with bio module PSM device which did not interfere with participants' work performance ability. Figure 2 shows the different physiological status monitoring parameters such as posture, heart rate, ECG and physiological intensity of a participant for the certain time interval during the experiment measured by PSM device. The increase in the heart rate, physiological intensity and ECG can be observed each time participant bends and lifts the object as well corresponding change in posture can be observed.

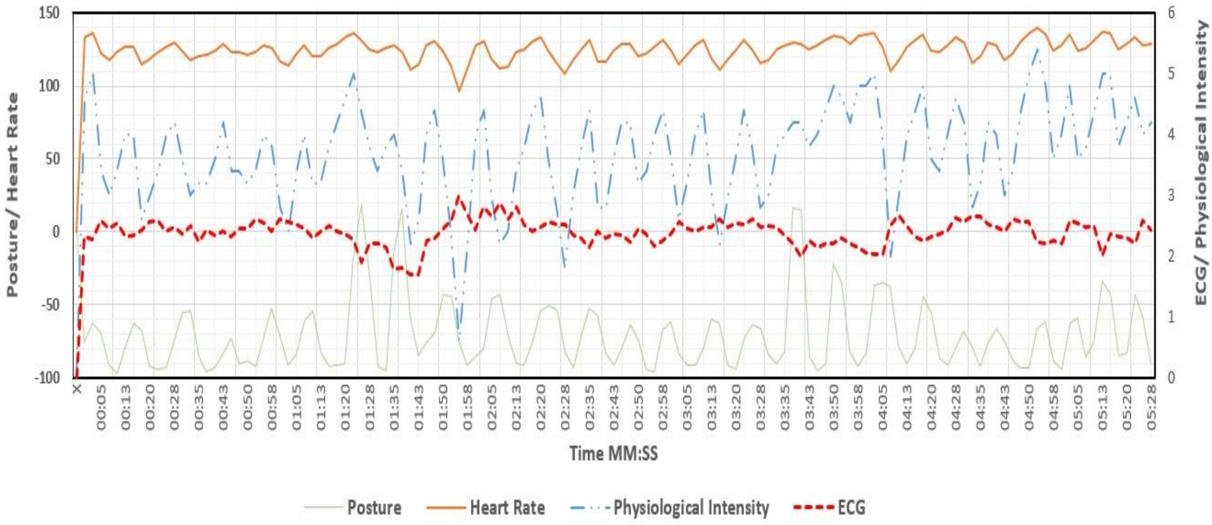

Fig. 2. Posture (°), Heart Rate (BPM), ECG (EKG) and Physiological Intensity of a participant during experiment by PSM Device

Each activity has its unique requirement and unique challenges. Each construction site is unique. So, a posture analysis done in a construction site might not accurately reflect the challenges at another construction site. Due to this fact, the experiment was conducted in two settings. The two settings are described below.

a) Normal lifts

Normal lifts are lifts that laborers would normally perform in their day-to-day activity. These will portray the persona of the laborers in terms of their posture while working. It is during this session that the unsafe lifts will be identified and areas of improvement for the laborers are determined.

In the case of the pilot study, lifts of varying body posture were performed to test the feasibility of using Kinect for the experiment. Figure 5 and Figure 6 demonstrate some postures that the laborers can take while performing the same lifts.

b) OSHA recommended safe lifts for the same situation

Although the idea of the method is to learn from the peers, for the pilot study, standard safe lifting posture was created by simulating OSHA recommended safe lifting posture multiple times by a participant. The posture data collected from such lifts will serve as the datum for assessing the lifts discussed in previous section. OSHA guidelines describes the proper way for lifting but does not specify exact angles for body joints. It is also because tracking human body joint angles was not feasible before technologies like depth camera. Hence, to quantify the OSHA regulations for the case, data on best practice needs to be collected. Figure 3 shows the standing and OSHA recommended squat position of the safe lift.

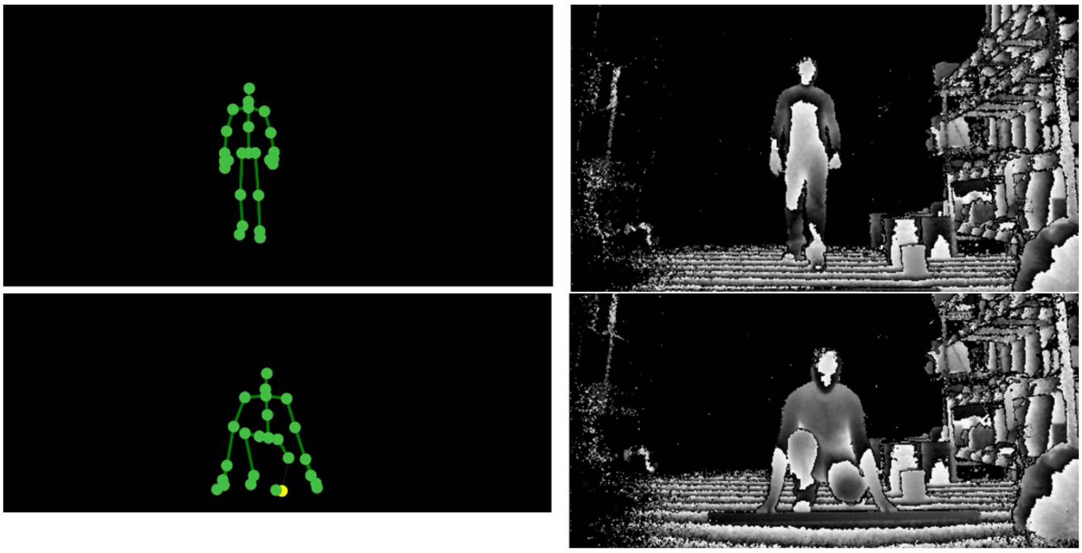

Fig. 3. Skeleton and depth image from Kinect standing posture (top), lifting posture (bottom)

2) Data and Activity Analysis

Data collected from the site should be filtered and analyzed to identify different activities that occurred. For the pilot project, the lifts were identified manually from the Kinect video playback and the data pertaining to the lifts were extracted for analysis. Figure 4 shows the different types of lifts performed by the participants and data corresponding to each lift. The charts on the right to each screenshot are extracted for further analysis. The charts show the change of posture angle as the participant completes a single lift operation. Since the analysis is being done for safety, the time taken for all the lifts have been normalized for comparison. The angle represents the angle of the torso to the vertical. Lifts with possible smallest torso angle to the vertical is considered to be the safest posture as it exerts minimum stress to the back.

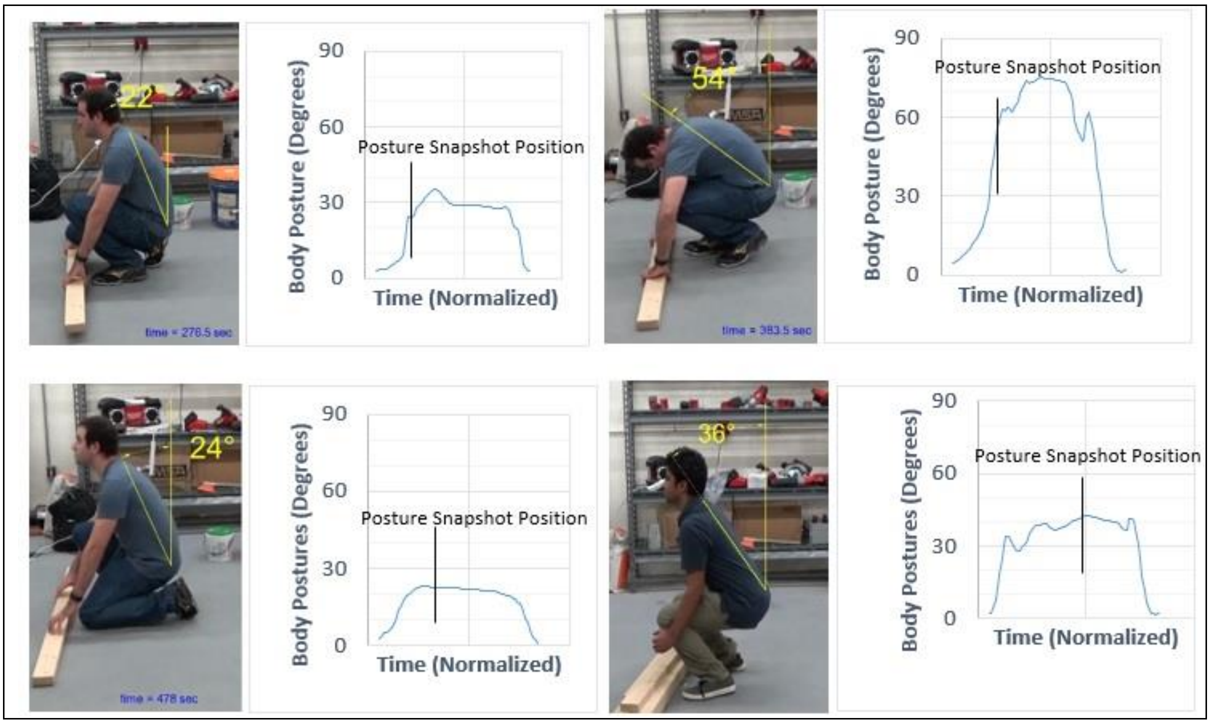

Fig. 4. Snapshots of different posture position during lifting and corresponding posture data

After activity analysis and data extraction, a model needs to be developed for each participant on how the participant performs the lifts. The virtual reality studio could be used to create the animated model from the extracted data which participant can observe and identify the area for improvements. Figure 5 shows the lifts performed by the participant while following OSHA guidelines and Figure 6 shows the lifts performed by the participant while performing lifts with random posture.

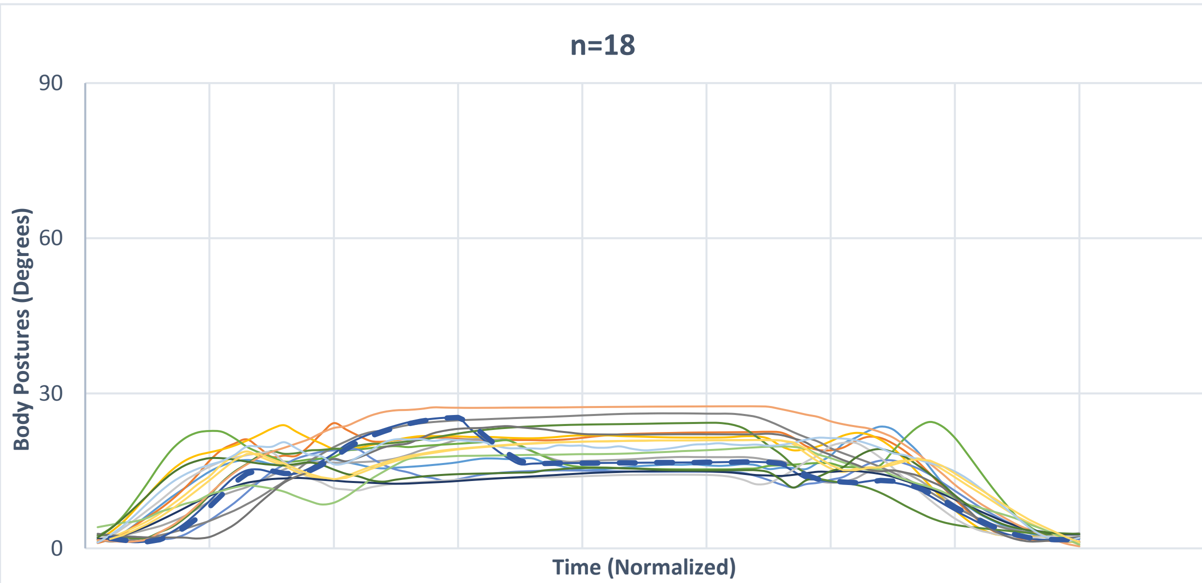

Fig. 5. Posture data for lifts with squat position as per OSHA standards

It can clearly be seen that the participant bend the torso significantly less while following OSHA's recommendation. Hence, although OSHA does not specify an angle for quantitative classification of good posture, a rough range can be obtained from experiment done in similar site situation. It should be noted that the timespans of each lifts in Figure 5 and Figure 6 are different but they have been normalized for easy comparison.

As well, it should be noted that each plot line in Figure 5 and Figure 6 represents a single lifting tasks incorporating approach to the object, bending to lift the object, lifting the object, standing up with the lifted object and walking with straight back to the place where object needs to be put down.

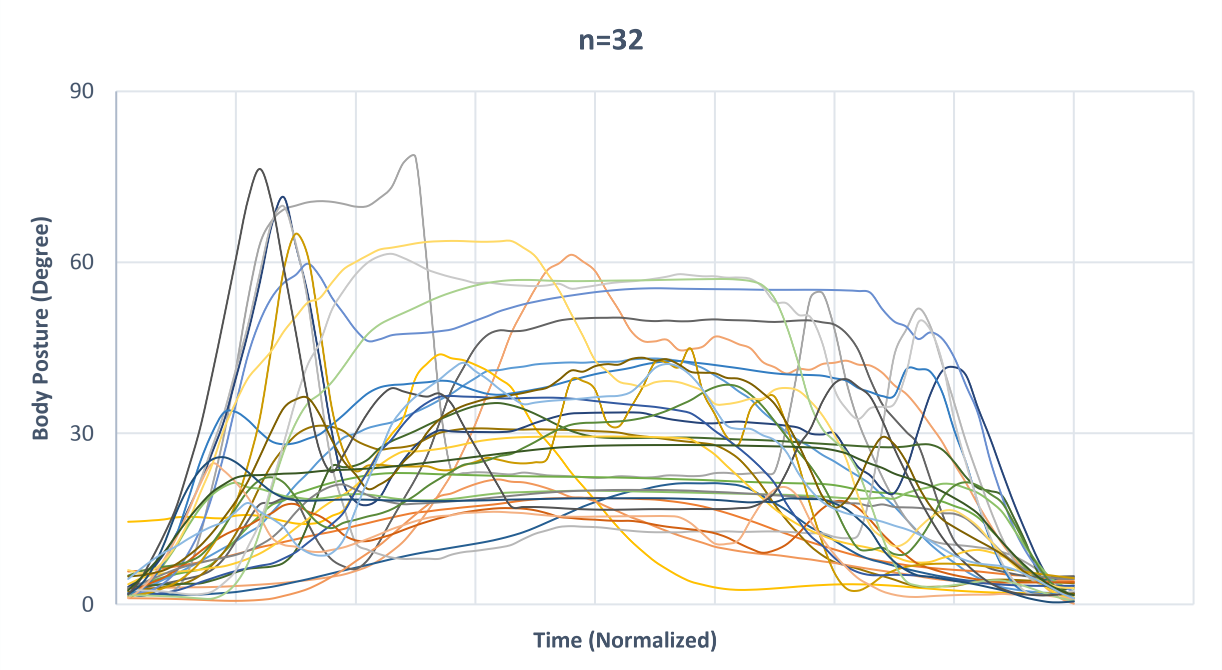

Fig. 6. Posture data for lifts with random postures

Since the lifts were performed randomly, no trends can be observed for statistical modeling of the nature of lift. But in normal conditions, each participant is expected to exhibit a peculiar nature which can be studied and assessed for areas of improvement. Figure 5 shows more homogeneity in lifts compared to Figure 6 because the lifts in Figure 5 were performed to meet the OSHA Standards.

3) VR-based Personalized Feedback

The safe lifting technique meeting the OSHA Standards can be created at controlled laboratory. And the posture data collected from the experiment can be imported and assigned to an avatar in virtual reality. Now, the avatar will replicate the exact same movement that was made in the controlled laboratory in virtual reality. Then again the posture data can be collected from the participant and the corresponding animation can be created in virtual reality. That way, the feedback can be given to the participant in visual form by comparing their lifting with the safe lifting technique. The visual instruction has been found to have the longest lasting impact compared to audio or written instructions (Penney, C G., 1989). The avatar can highlight the areas of improvement for the participant and the participant can learn interactively through the virtual reality. Figure 7 shows a sample lift performed by an avatar based on the data collected from the participant.

Fig. 7. VR-based Personalized Feedback Environment

This method of training can potentially create a deeper impression about safe practices in laborers on a construction site. The method offers learning from actual data collected from the same site and interactive visual learning environment. More experiments need to be conducted to validate the hypothesis that this method is more effective than traditional instructional method of safety training.

Discussion and Conclusion

The method of personalized learning based on real-time data from the laborers can potentially yield better results compared to traditional instructional training method followed in current practice. Since the laborers are tracked, the feedback is directly relevant to each of the laborers and they can interactively learn from their own data as well as data collected from their peers. The application of the technology is limited to the performance of the Kinect camera. Other vision-based and marker-based methods can also yield the same data that can be leveraged for the personalized learning system. Hence, irrespective of the technology being used and the operation being analyzed, the concept of individualized feedback based on automatic analysis of own data offers a promising way of teaching and learning in the future. This method can potentially improve safety training techniques and eventually prevent accidents and save lives.

The preliminary result from the experiment shows the potential capacity of construction site safety monitoring autonomously and effectively. And the use of depth sensor camera such as Kinect and computer vision technique for construction site laborers' tracking have been validated by many researchers (Cheng, Tao et al., 2013; Khosrowpour 2014; Rafibakhsh, Nima et al., 2012; and Li, C. and Lee, S., 2011). These depth sensor cameras have great potential for skeletal tracking on construction sites since their cost is low and have the ability to track the laborers in real time. The only limitation with current depth sensor cameras is the distance they can track which could be compensated by the use of multiple cameras (K. Suttipong, et al., 2013).

Since safety of laborers in the construction site has been the primary concern to all the construction managers, deployment of PSM device and depth sensor camera in the site for providing real-time performance feedback have a good potential in reducing the construction hazards. The cost of these depth sensor camera and PSM devices are low compared to the cost of potential injuries and fatalities and they are non-intrusive to laborers' productivity. This implies that the practical implementation is feasible with appropriate technological development. The accuracy and frequency of the data collected are the major challenges to be addressed regarding the PSM device whereas the limitation with distance that a depth sensor camera can track with accuracy is another challenge needed to be addressed regarding the depth sensor camera. With rapidly advancing recent technologies, if these challenges are addressed, then VR based personalized feedback could be a milestone for training novice of laborers based on their previous performance, thus aiding to create the safe working environment.

Further work needs to be done including the larger dataset from the real construction laborers to validate the use of depth sensor cameras for the real time personalized feedback by comparing the performance of laborers before and after getting feedback from VR based personalized feedback environment.

References

Bureau of Labor Statistics (2016) “NAICS 23 Work related fatalities, injuries and illnesses” < http://www.bls.gov/iag/tgs/iag23.htm> (Accessed: September 28, 2016)

Cheng, T., Migliaccio, G. C., Teizer, J., & Gatti, U. C. (2012). Data fusion of real-time location sensing and physiological status monitoring for ergonomics analysis of construction workers. *Journal of Computing in Civil Engineering*, *27*(3), 320-335.

Hartmann, B., & Fleischer, A. G. (2005). Physical load exposure at construction sites. *Scandinavian journal of work, environment & health*, 88-95.

Koningsveld, E. A., & Van der Molen, H. F. (1997). History and future of ergonomics in building and construction. *Ergonomics*, *40*(10), 1025-1034.

National Academy of Engineering (2016), NAE Grand Challenges for Engineering <http://engineeringchallenges.org/challenges.aspx> (accesses October 15, 2016)

Pradhananga, N. (2014). Construction site safety analysis for human-equipment interaction using spatio-temporal data. Doctoral dissertation. Georgia Institute of Technology.

Ray, S. J., & Teizer, J. (2012). Real-time construction worker posture analysis for ergonomics training. *Advanced Engineering Informatics*, *26*(2), 439-455.

Schneider, S., & Susi, P. (1994). Ergonomics and construction: a review of potential hazards in new construction. *American Industrial Hygiene Association*, *55*(7), 635-649.

Teizer, J., Cheng, T., & Fang, Y. (2013). Location tracking and data visualization technology to advance construction ironworkers' education and training in safety and productivity. *Automation in Construction*, *35*, 53-68.

Li, Chunxia, and S. Lee. "Computer vision techniques for worker motion analysis to reduce musculoskeletal disorders in construction." *Computing in Civil Engineering* (2011): 380-387.

Cheng, Tao, et al. "Automated task-level activity analysis through fusion of real time location sensors and worker's thoracic posture data." Automation in Construction 29 (2013): 24-39.

Khosrowpour, Ardalan, Juan Carlos Niebles, and Mani Golparvar-Fard. "Vision-based workface assessment using depth images for activity analysis of interior construction operations." Automation in Construction 48 (2014): 74-87.

Rafibakhsh, Nima, et al. "Analysis of xbox kinect sensor data for use on construction sites: depth accuracy and sensor interference assessment." Constitution research congress. 2012.

Li, Chunxia, and S. Lee. "Computer vision techniques for worker motion analysis to reduce musculoskeletal disorders in construction." Computing in Civil Engineering (2011): 380-387.

Kaenchan, Suttipong, et al. "Automatic multiple kinect cameras setting for simple walking posture analysis." Computer Science and Engineering Conference (ICSEC), 2013 International. IEEE, 2013.

Penney, C G. “Modality Effects in Delayed Free Recall and Recognition: Visual Is Better than Auditory.” The Quarterly journal of experimental psychology. A, Human experimental psychology 41.3 (1989): 455–470. Web.