Towards a Cyber-Physical Gaming System for Training in the Construction and Engineering Industry

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TOWARDS A CYBER-PHYSICAL GAMING SYSTEM FOR TRAINING IN THE CONSTRUCTION AND ENGINEERING INDUSTRY

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Abstract

Introducing serious gaming systems (SGS) has the potential to enhance trainee experience and performance across the construction industry and its supply chain, such as mechanical engineering services. SGS as an 'enabler' in architectural engineering has received limited research in its role to assess and enhance the performance of its workforce. In a personnel high-risk environment, improving training standards to eliminate or reduce health and safety risks, in addition to providing an understanding of workers' ergonomics, ensures sustainability of both the project and its workforce.

This paper presents an activity tracking and feedback system that captures the physical activity of a construction worker climbing a ladder. Climbing is captured with a 3D motion capture system and processed in real-time to identify potential areas of underperformance. A simple and representative scoring method was established as a reporting method (game statistics) for giving feedback about the correctness of the activity. It can nonetheless be tuned to characterise and adjust to various complexity levels in-line with the required training standards. Furthermore, the motion data and feedback information are fed into a virtual gaming environment enabling the real-time visualisation of the trainee's motion and experiential learning of the performance through visual and audio feedback. The gaming concepts are employed here with multiple purposes, particularly for accelerating and facilitating the learning process of the trainee. In addition to the 3D motion capturing system, this paper outlines and tests a proposed serious cyber-physical gaming system that incorporates wearable technologies that has the potential to support both construction training and practice.

1. INTRODUCTION

The construction and engineering industry remains high risk given the number of fatalities on-site as evident by the industry statistics. The International Labour Organization (ILO) agency's latest worldwide statistical data on occupational accidents and diseases, and work-related deaths revealed that the construction industry has a disproportionately high rate of recorded accidents [1]. Similarly, statistics of higher levels of fatalities in construction industry has been reported in Europe and US [2, p. 3], [3, p. 14,15]. The UK based Health and Safety Executive employers' handbook reports that incidents involve ladders and stepladders account for 14 deaths and 1200 major injuries to workers each year [4]. Lack of training has been identified as one of the major root cause for many of these accidents [5]. A well-trained construction workforce, including throughout its supply chain (e.g. mechanical engineering services) is more likely to perform better on-site and maintain the highest level of safety standards thereby reducing accidents. Tougher training standards could help towards reducing construction fatalities and enhancing workforce performance. Higher training standards could be achievable by investment in technology and development of innovative modes of delivering training and performance assessment. There is evidence that simulation and game-based training technologies, by nature of their contextually-rich and interactive environment, can provide for experiential learning which is transferable to the real world [6]. It is reported that, as a result of using simulators in the mining industry, there was a 20% improvement in truck operating efficiency and reduction in metal-to-metal accidents [7].

It follows that simulation-based learning can address the fundamental need to reinvigorate instructional methods where students currently need to adapt to traditional delivery methods instead of delivery adapt to the students [8]. In particular, the use of gaming (as a form of simulation-based learning) has the potential to improve engagement and skills development in Vocational Education and Training (VET) given by the advancement in technology and visualisation interfaces [8], [9]. Games are action and goal directed and when used as educational tools can allow learners to be active agents rather than passive consumers of received knowledge [10].

As such, this paper reports on a preliminary application of a cyber-physical serious gaming system (CP-SGS) in the context of ladder climbing training, CP-SGS involves the integration of game-based learning (GBL) and activity tracking technologies. In contrast to simulation-based learning environments presently used in construction training, the CP-SGS aims to provide a learning/training platform that includes human factor and ergonomic analytics (diagnostic and prognostic) which will be further discussed in the subsequent literature review section. This is then followed by a description of the components that make-up the CP-SGS, and presentation of preliminary findings. This is followed by a discussion accompanied by a detailed plan for future work.

2. TRACKING AND GAMING TECHNOLOGIES IN CONSTRUCTION ACTIVITIES

Activity tracking in construction involves continuous monitoring of physical activities of workers, and can provide objective information on performance in relation to occupational safety, ergonomics and physiological aspects, and productivity. Appropriate body poses and systematic methods of carrying out physical activities would not only improve labour efficiency but also address workers' long term health and well-being [11]–[14]. Previous research has investigated various technologies for sensing worker body motions at different levels of granularity. They include vision [12], [15], [16], depth sensors [13], [15], [17], GPS [18], RFID and Ultra Wide Band (UWB) [14], [19], [20].

All these technologies are attractive since they are available at declining costs and increased reliability. However, they all present some troublesome limitations preventing their simple and rapid deployment for ubiquitous and fine body motion tracking. Vision and depth-sensor systems require dedicated physical infrastructure to be installed at the location where the activity is being conducted, only work with line-of-sight, and are affected by the lighting conditions. UWB and RFID also require dedicated infrastructure to be installed, and their positioning accuracies are too limited for fine body motion tracking [21]. Finally, GPS requires virtually no infrastructure, but does not work indoors or in other signal-disrupting contexts.

Alternatively, exoskeleton style devices support the collection of complex kinematic motion data, and are particularly applicable to spinals movements [22]. For example, Alwasel et al. [23] recently proposed to use magneto-resistive angle sensors for measuring body posture angles (e.g. shoulder joint and knee angles) and characterising injuries. Despite the clear advantages of these systems in terms of infrastructure and data quality and detail, they present the important limitation of being invasive, which can impact worker mobility and productivity.

2.1. ACTIVITY TRACKING FOR LADDER CLIMBING

The latest figures from the Health and Safety Executive [24] reveal that falling from heights still accounts for nearly 50% of construction fatalities. Falls from edges and opening account for 28% of falls, followed by falls from ladders (26%), and finally scaffolding and platforms (24%) [24]. Similar statistics have been reported by Rivara and. Thompson [25].

Quantifying the effectiveness of training is difficult and only surveys and other subjective techniques (such as site observations) are commonly used as a means for evaluating the effectiveness of training programmes [21]. Using technology in training environments for automated tracking of activity, detection of unsafe behaviour, and review of such information can become a powerful tool to engage workers and emphasise safer work practices. Using objective and quantitative feedback provide the basis for comparison and benchmarking of inexperienced trainees against experienced ones, with reward systems for safe performance during training sessions [21]. Identifying ladder-climbing activity as a prominent safety critical activity in commonplace construction tasks, this paper analyses the activity consisting of a trainee climbing the ladder during a training session. This activity has been evaluated for any under-performance with the perspective of safety. The analysis is primarily performed based on a simple notion: "maintaining three points of contact during climbing a ladder", a directive commonly recommended in construction practices [26], [27].

2.2. GAMING IN CONSTRUCTION EDUCATION AND TRAINING

The use of virtual reality based gaming in construction education and training is not new and can be dated back to 1977 when Harris and Evans [28] used a computer game that was designed primarily for management training to simulate different work scenarios on construction projects such as machine breakdown, bad weather, unavailability of materials, etc. The notion of game-based learning (GBL) generally entails the delivery of interactive content to engage learners. While there is a plethora of reports and articles on the qualities and benefits of GBL, notably very few of these are related to vocational-learning [29]. GBL can take the form of role play, playing with real objects and models, and interactive computer games or Digital game-based learning (DGBL). Forsythe [30] used a construction game in the form of physical model making as a means of applied learning and found to increase student engagement and reinforce lecture content.

DGBL includes simple simulation of training scenarios through an online portal. For example, MERIT (Management Enterprise Risk Innovation and Teamwork) is a computer-based simulation that generates realistic scenarios of a construction company's business markets and conditions, and with which young engineers interact as teams to competitively manage their virtual company [31]. More sophisticated approaches of DGBL include the use of immersive environments to provide a simulated experience of a construction project environment (e.g. ACT-UK [32]).

Gaming in construction education and training can be adopted to make students learn and appreciate the complex nature of managing work on-site, for example, structural design and building services. Application of games in construction management training enables participants to be put into complex realistic situations without being exposed to the health and safety risks and financial penalties of real projects [33]. In general, playing computer games is linked to a range of perceptual, cognitive, behavioural, affective and motivational impacts and outcomes. The most frequently occurring outcomes and impacts are knowledge acquisition/content understanding and affective and motivational outcomes [6].

3. SYSTEM DESCRIPTION AND EXPERIMENTATION

3.1. CP-SGS FOR CONSTRUCTION TRAINING

The developed system primarily intends to capture the physical motion of the training activity and provide feedback, therefore the performance of the trainee can be evaluated and underperformances can be corrected. This solution employs contemporary motion tracking technology to precisely track body movements of the trainee. Captured motion data is then analysed both in a post process and in real-time for generating a detailed report and instantaneous feedback respectively. Ultimately, the system aims to interconnect the physical activity of the trainee to a gaming environment ultimately shaping a cyber-physical environment (Fig.1).

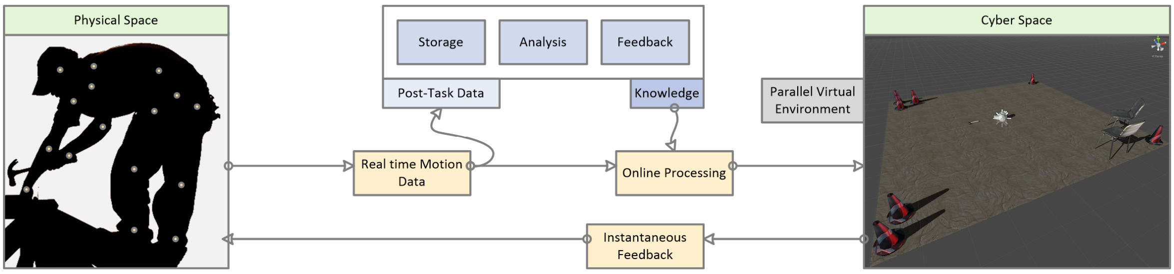

Fig.1 Cyber-physical serious gaming system for construction training

3.2. EXPERIMENT SETUP - ACTIVITY TRACKING FOR LADDER CLIMBING

Motion capture for ladder climbing Activity tracking was performed using the OptiTrack Flex motion capture system with 12 cameras. This motion tracker system requires wearing infrared reflective markers for tracking the motion. A ladder was setup inside the track-able volume of the system (Fig.2). Four infrared markers were worn by the trainee, one on each wrist and one on each ankle. Although more markers can be worn and tracked, the number of markers for this specific application was kept minimal for simplicity. The tracker system was setup to maintain the accuracy and the tracked volume; nevertheless it can be further improved by increasing the number of cameras, if required. The motion tracker system is capable of performing necessary processing and delivering 3D coordinates of the physical space with a defined origin.

Fig.2 Motion tracking setup for tracking the ladder climbing activity

3.3. MOTION DATA PROCESSING

Captured motion data of a trainee climbing a ladder mapped onto the physical 3D space is shown in Fig.4 with multiple viewpoints and orientations. In order to enable the visualisation of the data in relation to a ladder as well as its interpretation, it is also important to measure and align the physical location of the ladder with the tracked data's coordinate system. This problem is effectively solved in a preliminary stage by time tagging the coordinates of key ladder points (e.g. extremities of each step). Basically, each required point in the ladder was illuminated by an infrared marker for a brief time period. A simple process acquires all required points in one go, by moving a marker from one point to another and holding it stably at each point for a brief period of time (i.e. 1s or longer). The acquired motion data of the marker during the time tagging process had been is then processed to detect any stable points without movements. Fig.3 shows automatically detected time-tagged ladder coordinates.

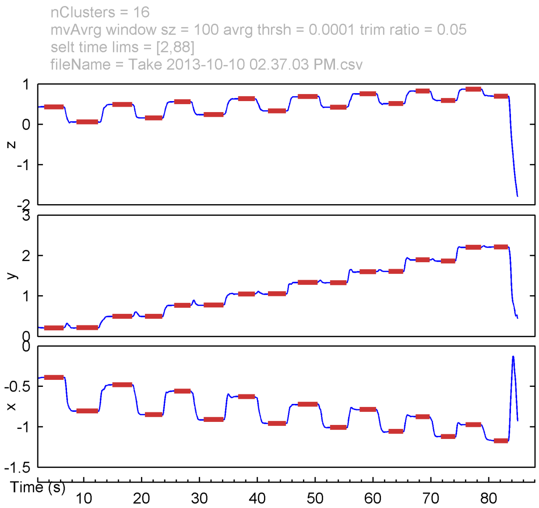

Fig.3 Time tagging and detecting physical ladder coordinates

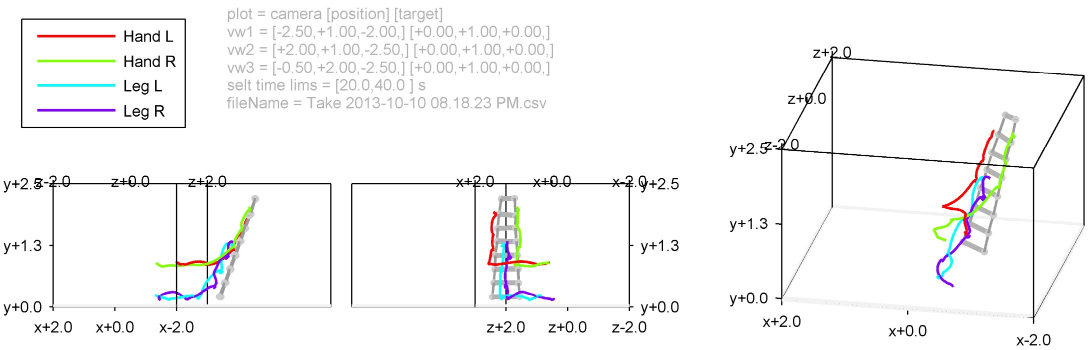

Fig.4 3D motion data of ladder climbing activity, physical 3D space dimensions are indicated in meters.

The motion data of the ladder climbing task is then automatically processed to detect movements in each limb, i.e. in left/right hands and legs.

The instantaneous velocity of each limb can be derived as:

$$v_t = \frac{ds}{dt} = \frac{\Delta s_t}{\Delta t}$$

where, the time interval (Δt) can be estimated from the sampling rate of the motion tracking system and the displacement (Δs_t) at any instance of time can be calculated from the captured 3D coordinates.

$$s_t = \sqrt{x_t^2 + y_t^2 + z_t^2}$$

To detect intense movements, the estimated instantaneous velocities are compared to threshold levels. A trainee ascending and descending two ladder steps is illustrated in Fig.5, which shows instantaneous velocities of each limb and the detected intense movements (highlighted in grey). The intense movements correspond to the movement of a hand or leg from one point to another, whereas no-movement in a limb implies firmly maintaining a hold on the ladder.

A representative scoring method has been established as an indication of the correctness of the climbing task as below.

$$score = 1 - \frac{\begin{array}{r} p_0 \sum_t \Delta t\,[nL_t = 0] + \\ p_1 \sum_t \Delta t\,[nL_t = 1] + \\ p_2 \sum_t \Delta t\,[nL_t = 2] + \\ p_3 \sum_t \Delta t\,[nL_t = 3] + \\ p_4 \sum_t \Delta t\,[nL_t = 4] \end{array}}{\sum_t \Delta t\,[nL_t \in \{1,2,3,4\}]}$$

Where nL_t denotes total number of limbs moved simultaneously, at an instance of time and $p_1..p_4$ denotes a penalising factor. This representative scoring method works based on the time duration of the limb movements and penalises moving more than one limb at any instance of time. Moving one limb alone is always permissible and therefore it is essential that, $p_1 = 0$; whereas moving more than one limb should be penalised by adjusting the $p_2..p_4$ factors. Incrementing the penalising factor for example $p_2 = 0.1, p_3 = 0.2, p_4 = 0.3$ means that the score is lowered incrementally as the relative duration when limbs simultaneously moved increases. This way, a person always maintaining three points of contact, i.e., never moved more than one limb at any moment of time will score 100%. Note that the score can also be lowered for idling, i.e., moving no limbs at all, by increasing the factor p_0.

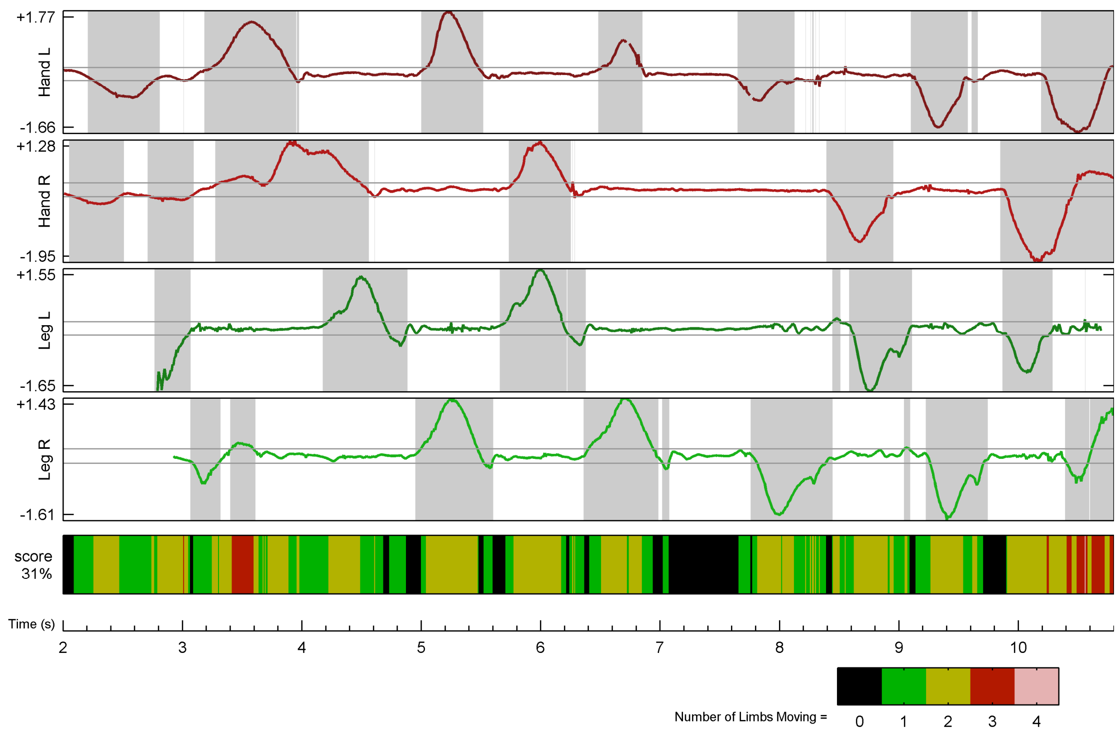

Fig.5 Movements detected on each limb and the score established based on the number of limbs moving at an instance of time.

3.4. VIRTUAL ENVIRONMENT

Besides generating a score, a cyber-physical system was developed to provide instantaneous feedback. A virtual environment for ladder climbing was developed using the Unity game development toolkit is shown in Fig.6. This system was fundamentally designed to simulate a parallel virtual environment to the physical environment. Algorithms and scoring method established previously were ported in this game development environment. This system enables feeding the live motion tracking data streams (i.e., via TCP packets) into the virtual environment, while playing back the recorded data is also supported. Features embedded in this environment are listed below.

- 3D objects (hands, foot) corresponding to each limb is rendered in the virtual environment; the movement of the virtual objects in the virtual 3D space is directly mapped from the movement of the corresponding limbs in the physical space's coordinate system.

- Hand/Foot objects change their colour from blue to pink linearly based on the intensity of the movement (i.e., physical velocity). Here, no movement is indicated by the blue colour while increased pink means an increase in the motion.

- An overhead light is used to indicate the instantaneous performance. The colour of the light changes according to the number of limbs moved simultaneously. The colour codes are chosen to be identical to the colour codes presented in 3.3.Fig.5.

- A 3D reverb audio zone is built into the virtual space where a non-intrusive but distinguishable noise is rendered. This noise changes its frequency – this is composed by some interpretable sound intensity variations that can be overheard. The frequency of this noise increases as the movement intensity on limbs is increased. For example, two limbs moving simultaneously will produce a higher pitch sound than one limb moving alone.

The scene camera views all the objects in the environment, e.g., moving objects, ground, and surroundings. This camera can be controlled via any game controllers (e.g., using axis in keyboard, mouse, joystick etc.) to orbit around the centre, pan or zoom.

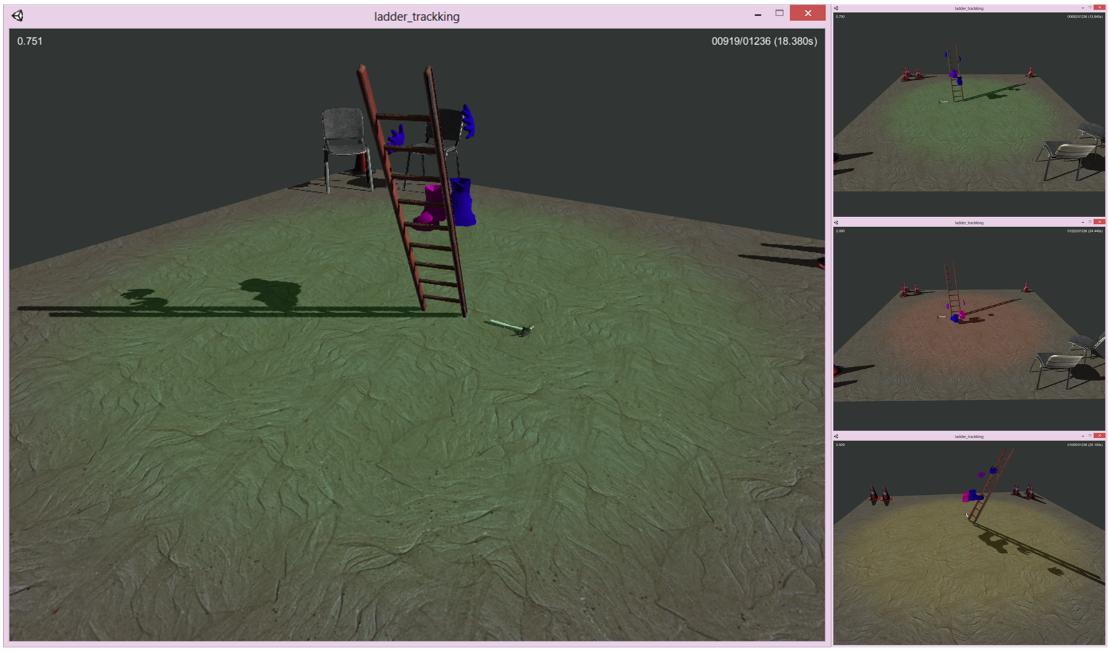

Fig.6 A parallel virtual environment developed for simulating ladder climbing activity

4. DISCUSSION

Quantifying the effectiveness of training is difficult and only surveys and other subjective techniques (such as site observations) are commonly used as a means for evaluating the effectiveness of training programmes [21]. The cyber-physical serious gaming system for construction training presented in this paper primarily demonstrated its capability to provide real-time quantitative feedback on trainee's performance. Results presented here show that trainee physical activities can be tracked and analysed in levels of details that are difficult to be achieved by human trainers. This also provides opportunities of capturing expert skills from experienced workers with the view to transferring them to apprentices. Various activity patterns i.e. skills and knowledge, developed through years of experience can be captured and analysed quantitatively. Subsequently, apprentices can be encouraged to follow the identified good practices. While this system has been demonstrated using an example scenario of climbing ladder, its scope is not limited to this example; the same technique can be applied in various other construction and engineering scenarios such as mechanical assembly, hammering, brick-laying, to name a few.

In addition to virtual 3D rendered scenes and feedbacks, the gaming engine employed here provides various other opportunities such as physics simulations. Worst case scenarios such as accidents are undesirable and rare incidents in a worker's career; therefore physically providing experience to safely handle these events is nearly impractical. Simulations in the virtual environment of such incidents become useful to identify potential hazards during the training and to learn about possible preventive measures. The proposed system enables the simulation of such incidents based on actual physical actions/motions by the trainee, which enable them to associate themselves far more to the simulated scenarios.

The current cyber-physical system provides feedback primarily from the virtual environment. However it is generally straightforward to wire-up feedback modals into the physical environment, for instance, a speaker system can be setup within the real environment to interconnect the sound output from the game engine. A real overhead lighting, similar to the virtual environment can be easily added to the system by extending a game module using custom scripts and adding some few extra hardware components. Although embedding a display into the physical activity might add intrusiveness to the physical activity being performed, revolutionary augmented/mixed reality technologies can provide opportunities for introducing visual interfaces in the physical environment.

5. FUTURE WORKS/VISION

Further to interconnecting the feedbacks from the virtual cyber space to the physical space in real time with various modalities, it becomes possible to foresee an arrangement leading towards interconnected, wearable computing devices that can serve the purpose of capturing the physical activity, processing the captured data, proving feedback in real-time. Consequently a cyber-physical system for tracking workforce's activities with the views of health, safety and performance is being proposed in this paper. Fig.7 illustrates the conceptual cyber-physical system with wearable computing devices. This system will potentially enable analysing the physical activities of the workforce beyond the training scenario but with the perspective of a life-long learning system.

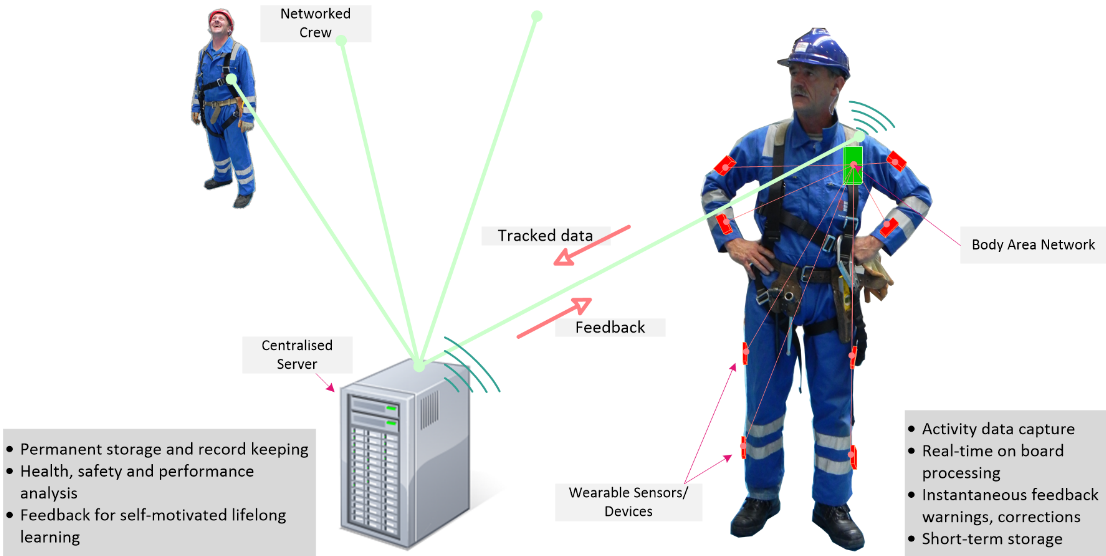

Fig.7 Proposed cyber-physical body-area networked system with wearable computing tools

It might be appropriate to have alternative modalities to capture physical activities and provide feedback. For instance instead of using the vision-based tracking technology, which is mostly suited for laboratory/indoor environments, inertial measurement units (accelerometer, gyroscope) and compass (compass) are preferable for a wearable, body area network arrangement. Not limited to the motion tracking, modern day wearable sensing devices are available for measuring various other physical parameters, e.g., global position system location, carbon monoxide levels, etc. and physiological parameters, e.g., body temperature, heart rate, respiration, electromyography, electroencephalography, etc. In addition to the sensors feedback can also be provided using wearable components, e.g. vibratory, haptic, augmented displays, etc.

On-going work involves developing a wireless and wearable platform which is robust, and flexibly accommodates interfacing with various sensing and feedback devices. The intended platform is primarily focused in interconnecting the cyber-space with the physical-space via body area network based devices. This in-turn opens up unprecedented opportunities in capturing the physical activities of human workforce and providing immediate and post-action feedback. For instance, as illustrated in Fig.7, a wearable module with computational and storage capabilities can collect information from multiple sensors in the network, process it in real-time and provide instantaneous feedback. Additionally the system may store the captured data internally for a short period of time before the data get uploaded to a centralised server e.g., at the end of each day. While the instantaneous feedback is focused on trigging corrective actions (e.g., wrong postures, reminders to take break, etc.), the purpose of the centralised system is to keep track of a worker's life-long performance, health records.

6. CONCLUSION

This paper presented a novel cyber-physical gaming system that enhances the quality and delivery of the training. This study demonstrated the potentials of this system using ladder climbing activity as an example, although its scope is not limited to one particular type of activity. Further to the analysis and the demonstration of the concept of cyber physical serious gaming system, this work proposed a unique body area network based system for linking the physical and cyber spaces, and that is intended to provide instantaneous corrective feedback, life-long learning, health, safety and performance tracking and feedback.

Arguably, the more sophisticated the game interface becomes, the more likely it can provide better means for student engagement and learning. The overarching aim of DGBL is to employ the latest cutting-edge computing technologies to support student interaction and acquisition of new skills so that by the completion of their training they become on their way for becoming high performing (productive) workers whilst maintaining the highest health and safety standards.

References

[1] "Safety at work - Countries: Subregional Office for Eastern Europe and Central Asia (SRO-Moscow)." [Online]. Available: http://www.ilo.org/public/english/region/eurpro/moscow/areas/safety/statistic.htm. [Accessed: 05-May-2014].

[2] European Agency for Safety and Health at Work, "Actions to improve Safety and Health in Construction," *Office for Official Publications of the European Communities,*, vol. 7, 2004.

[3] U.S. Bureau of Labor Statistics, "U.S. Bureau of Labor Statistics, U.S. Department of Labor, 2014.," 2014.

[4] "Health and Safety Executive: Safe use of ladders and stepladders: An employers' guide. Part INDG402." 2011.

[5] T. Abdelhamid and J. Everett, "Identifying Root Causes of Construction Accidents," *J. Constr. Eng. Manag.*, vol. 126, no. 1, pp. 52–60, 2000.

[6] T. M. Connolly, E. A. Boyle, E. MacArthur, T. Hainey, and J. M. Boyle, "A systematic literature review of empirical evidence on computer games and serious games," *Comput. Educ.*, vol. 59, no. 2, pp. 661–686, Sep. 2012.

[7] "Immersive Technologies (2008). PT Freeport Indonesia Incorporates Locals to the Work Force," *Mining Magazine*, 2008.

[8] J. Goedert, Y. Cho, M. Subramaniam, H. Guo, and L. Xiao, "A framework for Virtual Interactive Construction Education (VICE)," *Autom. Constr.*, vol. 20, no. 1, pp. 76–87, Jan. 2011.

[9] M. O'Rourke, *Using immersive 3D computer games to help engage learners and deliver skill sets*. Melbourne: AVETRA, 2013.

[10] K. Squire, "From Content to context: videogames as designed experience," *Educ. Res.*, 2006.

[11] A. Peddi, L. Huan, Y. Bai, and S. Kim, "Development of Human Pose Analyzing Algorithms for the Determination of Construction Productivity in Real-Time," in *Construction Research Congress 2009*, American Society of Civil Engineers, 2009, pp. 11–20.

[12] C. Li and S. Lee, "Computer Vision Techniques for Worker Motion Analysis to Reduce Musculoskeletal Disorders in Construction," in *Computing in Civil Engineering (2011)*, American Society of Civil Engineers, 2011, pp. 380–387.

[13] V. Escorcia, M. Dávila, M. Golparvar-Fard, and J. Niebles, "Automated Vision-Based Recognition of Construction Worker Actions for Building Interior Construction Operations Using RGBD Cameras," in *Construction Research Congress 2012*, American Society of Civil Engineers, 2012, pp. 879–888.

[14] T. Cheng, G. Migliaccio, J. Teizer, and U. Gatti, "Data Fusion of Real-Time Location Sensing and Physiological Status Monitoring for Ergonomics Analysis of Construction Workers," *J. Comput. Civ. Eng.*, vol. 27, no. 3, pp. 320–335, 2013.

[15] J. Teizer and P. A. Vela, “Personnel tracking on construction sites using video cameras,” *Adv. Eng. Inform.*, vol. 23, no. 4, pp. 452–462, Oct. 2009.

[16] J. Gong and C. Caldas, “Learning and Classifying Motions of Construction Workers and Equipment Using Bag of Video Feature Words and Bayesian Learning Methods,” in *Computing in Civil Engineering (2011)*, American Society of Civil Engineers, 2011, pp. 274–281.

[17] S. J. Ray and J. Teizer, “Real-time construction worker posture analysis for ergonomics training,” *Adv. Eng. Inform.*, vol. 26, no. 2, pp. 439–455, Apr. 2012.

[18] R. Sacks, R. Navon, I. Brodetskaia, and A. Shapira, “Feasibility of Automated Monitoring of Lifting Equipment in Support of Project Control,” *J. Constr. Eng. Manag.*, vol. 131, no. 5, pp. 604–614, 2005.

[19] E. Jaselskis and T. El-Misalami, “Implementing Radio Frequency Identification in the Construction Process,” *J. Constr. Eng. Manag.*, vol. 129, no. 6, pp. 680–688, 2003.

[20] J. Yang, T. Cheng, J. Teizer, P. A. Vela, and Z. K. Shi, “A performance evaluation of vision and radio frequency tracking methods for interacting workforce,” *Adv. Eng. Inform.*, vol. 25, no. 4, pp. 736–747, Oct. 2011.

[21] J. Teizer, T. Cheng, and Y. Fang, “Location tracking and data visualization technology to advance construction ironworkers’ education and training in safety and productivity,” *Autom. Constr.*, Nov. 2013.

[22] W. S. Marras, F. A. Fathallah, R. J. Miller, S. W. Davis, and G. A. Mirka, “Accuracy of a three-dimensional lumbar motion monitor for recording dynamic trunk motion characteristics,” *Int. J. Ind. Ergon.*, vol. 9, no. 1, pp. 75–87, Jan. 1992.

[23] A. Alwasel, K. Elrayes, E. M. Abdel-Rahman, and C. Haas, “Sensing Construction Work-Related Musculoskeletal Disorders (WMSDs),” *ISARC Proc.*, 2011.

[24] “Construction Intelligence Report: Analysis of Construction Injury and ill health intelligence, Health and Safety Executive (HSE).” 2010.

[25] F. P. Rivara and D. C. Thompson, “Prevention of falls in the construction industry: Evidence for program effectiveness,” *Am. J. Prev. Med.*, vol. 18, no. 4, Supplement 1, pp. 23–26, May 2000.

[26] “HSE - Falls - Using laddes safely - ‘three points of contact’ on ladders.”[Online]. Available: http://www.hse.gov.uk/falls/usingladders/threepoints.htm. [Accessed: 22-Jan-2014].

[27] “basic ladder safety.” [Online]. Available: http://www.laddersafety.org/basicladdersafety.aspx. [Accessed: 22-Jan-2014].

[28] F. C. Harris and J. B. Evans, “Road Construction—Simulation Game for Site Managers,” *J. Constr. Div.*, vol. 103, no. 3, pp. 405–414, Sep. 1977.

[29] R. Blamire, “Digital Games for Learning Conclusions and recommendations from the IMAGINE project.” Nov-2010.

[30] P. Forsythe, “The Construction Game–Using Physical Model Making to Simulate Realism in Construction Education,” *J. Educ. Built Environ.*, vol. 4, no. 1, pp. 57–74, 2009.

[31] J. Wall and V. Ahmed, “Use of a simulation game in delivering blended lifelong learning in the construction industry – Opportunities and Challenges,” *Comput. Educ.*, vol. 50, no. 4, pp. 1383–1393, May 2008.

[32] “ACT-UK | Building Talent...” [Online]. Available: http://www.act-uk.co.uk/. [Accessed: 27-Jan-2014].

[33] S. H. AL-JIBOURI and M. J. MAWDESLEY, “Design and experience with a computer game for teaching construction project planning and control,” *Eng. Constr. Archit. Manag.*, vol. 8, no. 5/6, pp. 418–427, Dec. 2001.