Automation in Construction 49 (2015) 163–174

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Proactive training system for safe and efficient precast installation

Heng Li [a], Miaojia Lu [a], Greg Chan [a], Martin Skitmore [b]

[a] The Hong Kong Polytechnic University, Hong Kong, China
[b] Queensland University of Technology, Australia

ARTICLE INFO

Article history:
Received 30 December 2013
Received in revised form 10 September 2014
Accepted 21 October 2014
Available online 19 November 2014

Keywords:
Construction training
Construction safety
Work efficiency
Building Information Models
Real-time location system

ABSTRACT

The construction industry is a crucial component of the Hong Kong economy, and the safety and efficiency of workers are two of its main concerns. The current approach to training workers relies primarily on instilling practice and experience in conventional teacher–apprentice settings on and off site. Both have their limitations however, on-site training is very inefficient and interferes with progress on site, while off-site training provides little opportunity to develop the practical skills and awareness needed through hands-on experience. A more effective way is to train workers in safety awareness and efficient working by current novel information technologies. This paper describes a new and innovative prototype system — the Proactive Construction Management System (PCMS) — to train precast installation workers to be highly productive while being fully aware of the hazards involved. PCMS uses Chirp-Spread-Spectrum-based (CSS) real-time location technology and Unity3D-based data visualisation technology to track construction resources (people, equipment, materials, etc.) and provide real-time feedback and post-event visualisation analysis in a training environment. A trial of a precast facade installation on a real site demonstrates the benefits gained by PCMS in comparison with equivalent training using conventional methods. It is concluded that, although the study is based on specific industrial conditions found in Hong Kong construction projects, PCMS may well attract wider interest and use in future.
© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Supervising the safety of workers is one of today's most important challenges in the management and organisation of construction worldwide, as workers frequently face exposure to potentially hazardous situations such as falling from a height and striking against, or being struck by, moving objects. In the Hong Kong Special Administrative Region,[1] for example, construction is ranked as the most dangerous industry, with 46 fatalities in 2011 — around 24% of the total fatalities in all industries [1]. With a fatality rate of 0.337‰ in 2012 — an increase of 2.2% on the average of the previous five years [1] — the situation is worsening. With the recent introduction by the Hong Kong Government of ten major construction projects, the industry has experienced a shortage of labour, resulting in companies having to employ people with little relevant working experience. Moreover, the industry's high turnover rate is resulting in more experienced and productive workers being replaced by fresh ones with only baseline performance levels. A major outcome of this is the need for new workers to become as proficient as their predecessors as quickly as possible, especially in terms of efficiency and safety — two key factors closely associated with cost-effective and time-saving of construction projects [2] — making the provision of training in these two areas of significant importance for the industry.

Modern information technologies, which include real-time location and data visualisation, play a key role in providing support for data and messages travelling between management and workers within an intelligent communications network [3]. Real-time location and visualisation technologies have the potential to improve control of the safety and efficiency of workers by monitoring construction resources (people, equipment, materials, etc.) and identifying the status of work tasks anywhere and at any time

This paper presents a new approach, termed here the Proactive Construction Management System (PCMS), to the accelerated acquisition of safety and efficiency skills and awareness. This integrates data from sensors in training based on real-time tracking in order to measure and quantify safety and efficiency. Currently limited to location-based training for prefabricated product rigging and installation (like precast facade installation), the location of workers is tracked during hands-on training sessions involving the installation of temporary inclined bracing, fixing fabric reinforcement, etc. Chirp-Spread-Spectrum (CSS) technology is used to measure the location of the trainer and trainees, materials and cranes during tasks such as rigging, hoisting and fixing. The location-based data collected in this way is used to analyse their safety and efficiency.

Efficiency during the training session is visualised using a virtual reality environment for real-time and post-event analysis. To evaluate worker performance in the whole process, the track points of construction

E-mail addresses: bshengli@polyu.edu.hk (H. Li), emily.lu@connect.polyu.hk (M. Lu), 07900441r@connect.polyu.hk (G. Chan), rm.skitmore@qut.edu.au (M. Skitmore).

[1] Hong Kong's current formal name. However, we refer to simply *Hong Kong* here as an internationally recognised name.

http://dx.doi.org/10.1016/j.autcon.2014.10.010
0926-5805/© 2014 Elsevier B.V. All rights reserved.

resources are analysed to identify starting time points and accumulated durations of different construction tasks of each construction craft and the real-time feedback (instructions from trainers or real-time warnings) and post-event analysis can be provided to workers to help improve performance. Therefore the ability to convert data quickly into information about safety and productivity is crucial to construction training [4]. After sufficient training has taken place, baseline (pre-trained) and post-trained performance are loaded into comparison modules to identify improvements and calculate the estimated efficiency as a benchmark for further progress control decision making. The effectiveness of the system is then determined by an opinion-based investigation of trainers and trainees, with their feedback being used to identify the shortcomings and limitations of the technologies, so that the training plan can be updated and improved for future training.

This paper is organised as follows. Firstly, current construction training methods and potential state-of-the-art of real-time location and data visualisation technologies are reviewed in Section 2. This is followed by the description and implementation of the new system in Sections 3 and 4. Section 5 describes a real on-site trial for the further development and validation of the system, while Section 6 considers the benefits and limitations of PCMS training. Concluding remarks are provided in Section 7.

2. Background

2.1. Problems with current construction training

Construction work is sometimes very dangerous and physical components get damaged and workers injured if operations are not carried out correctly [5]. This problem is particularly acute in hoisting prefabricated components. In recent times, in order to improve both safety performance and the efficiency of workers on construction sites, more emphasis has been placed on providing adequate worker training [6]. Although requiring more initial investment, construction workforce training programmes are considered to be a significant advancement on the traditional master-apprentice approach. For example, it has been shown that investing 1% of a project's labour budget in both union and non-union training can result in double-digit returns in productivity, and reduced absenteeism and need for rework [7].

An apprenticeship programme in the US Department of Labour consists of 44 h a year of related off-site instruction, and at least 3 years, or 6,000 h, of on-the-job training (Bureau of Labour Statistics, U.S. Department of Labour). The typical *off-site* training process involves three phases based on equipment training websites, including West Coast Training Inc., The National Heavy Equipment Operator School, construction health and safety training classes and programmes as follows:

- *Classroom lecture*: Typical classroom activities include pre-work inspections (daily, weekly, monthly), potential hazard awareness, functions and operations of equipment and applications, how to work safely, show concern for fellow workers and look after the equipment, different types of construction equipment maintenance and repair regimes, and familiarisation with mobile construction equipment. Some additional learning modules are available to help meet special requirements. For example, a two-hour elective course on dumper truck operations introduces the concept of safety and communication between the truck driver and workers loading the trucks.
- *Hands-on instruction*: Hands-on construction work requires a site with room for practice exercises such as excavating, soil placement, trench sloping, benching, trench box/shoring placement and use, rigging and lifting, loading of trucks and stockpile re-handling. Usually an apprentice must practice and demonstrate knowledge of safe construction. In practice, apprentices must also demonstrate their understanding of how to perform general tasks safely and how to use specific equipment to accomplish a variety of tasks.
- *Testing*: Examinations can be conducted in written, oral or practical format. The written/oral test generally covers working skills and safety points made during the course. The practical examination tests individual performances in various tasks that maybe encountered on site (e.g., demonstrate an ability to follow directions, work safely, and show concern for equipment and fellow workers).
- *Other off-site training*: Self-study and peer-to-peer study are also an important and low-cost approach for workers to educate themselves through books, videotapes and co-workers.

However, these off-site training programmes provide trainees with limited hands-on experience of real working conditions and result in inefficient performance when apprentices first work on-site.

On-the-job training can be more effective but is time-intensive, expensive, and potentially hazardous, sometimes requiring specialised equipment. The time element is significant as a trainee needs considerable practice to develop the coordination necessary for the safe and efficient manoeuvring of materials. The expense results from the need for an on-the-job trainer and to effectively disable productive construction equipment so that a trainee can practice manipulating materials. Other additional costs incurred by training providers include buildings, maintenance, and machine operating costs, supervisors and external assessors. The sum of these costs can be considerable. This is exacerbated greatly by the need for apprentices to be continually supervised by more skilled and experienced colleagues for several months or even years [8].

An ideal training programme should enable workers to enhance working efficiency, upgrade safety awareness and practices more quickly, and reduce machine operation and training costs [5]. Compensating for the inherent drawbacks involved in current apprenticeship programmes, real-time data collection and visualisation technologies afford new opportunities for effectively training apprentices in achieving this, with lower costs, fewer hazards and increased efficiency.

2.2. State of the art

2.2.1. Background of real-time location technologies

To date, several real-time location technologies have been tested, the most promising of these being Radio Frequency Identification Devices (RFID) [9,10], Global Positioning Systems (GPS), Wireless Local Area Networks (WLAN), Ultra-Wide Band (UWB) and Indoor GPS, and hybrid systems comprising combinations of two or more technologies [11,12] to cover a wide range of accuracy values and yard areas [13,14]. Although all these technologies can be used to monitor the movement of construction resources, they need to satisfy the following criteria in construction work [15]:

- *Robust*. Working well in a variety of site layouts such as open or closed, cluttered, small or large, and open or indoor spaces
- *Operational range*. A sufficiently long range to guarantee good coverage of the entire site. This can vary between a few centimetres for RFID readers, over 100 m for WLAN and UWB access points and receivers respectively, and virtually limitless for GPS.
- *Accuracy*. Capable of accurately and precisely recording the positions associated with monitored work tasks. Accuracy ranges from 0.01 m for indoor GPS, less than 0.5 m for UWB, and up to several metres for standard GPS.
- *Device form and size*. Small enough to fit on an object without interfering with the work
- *Data update rate*. High data frequency provided in real-time (at least 1 Hz)
- *Social impact*. Non-invasive technology, but providing adequate safety and health protection.

Global positioning systems (GPS) are outdoor locating systems involving satellites, ground control stations and end users. GPS is a readily available technology and now one of the general specifications of

دریافت فوری ← متن کامل مقاله

ISIArticles
مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات