Abstract
Many of the activities in construction tend to lead to accident occurrences. The major causation of the accidents in this industry is fall from height. In developing countries such as Thailand, there are too many unsafe conditions in construction activities performed at high elevation. Although, the government enforces safety rules and regulations, safety facilities are still provided inadequately. The involved parties such as construction engineers and supervisors do not pay much attention to unsafe conditions, which may be caused by ignorance and unawareness of those personnel regarding hazards and risks. To eliminate unsafe conditions and to reduce a number of accidents, in-charge personnel should definitely have knowledge related with the requirements of safety procedures and safety facilities of construction activities performed at high elevation. It is more effective to enable those personnel gain experiences and perceive inherent hazards and risks of those activities in the actual construction environment. Thus, an innovative approach is needed to provide the personnel with visualized information of those activities as they occur in real construction site.

This study aims to develop a visualized approach for simulating the construction activities operated at high elevation using Augmented Reality to educate construction personnel. The improvement of construction personnel considerations in safety planning is investigated. The proposed system consists of the following: (1) hardware components, including a laptop computer, a video camera, and a head-mounted display (HMD), (2) three databases, i.e., database of virtual model of construction objects, database of hazards, risks, and consequences, and database of safe and unsafe scenarios, and (3) a computer program for generating and superimposing the simulations into the real world scene. This research is on-going and the prototype systems are under development. The prototype will be tested at a real construction site. In this stage, we propose the approach and system architecture.

Keywords: construction safety, planning, augmented reality, high elevation

1 Introduction
The accident costs in construction were reported for billions of dollars in economic loss. Additionally, the cost exceeds beyond its evidence. Indirect cost of accidents might be as much as six times the direct cost or more (Chen et al., 1995). The major cause of accidents in construction which leads to fatalities is fall from height (Hinze et al., 1998). The accidents frequently occur in building construction projects, particularly commercial buildings because most of them are high-rise buildings and comprise of multi-stories (Huang and Hinze, 2003).
Even though many safety guidelines, rules and regulations have been implemented and enforced at construction site in Thailand, safety measures such as guardrails, working platforms, safety nets, lanyards, climbing protection systems, and lifeline systems are still provided inadequately. From preliminary survey of construction sites, workplaces at high elevation are normally prepared unsafely and workers frequently take risks because they must finish tasks and activities. Figure 1 presents overviews of working areas and work practice at high elevation from construction site observations. The high risk activities are detected, for instance, in decorating of external facades, plastering and painting of external walls, erecting of reinforced steel bars, and dismantling of column formworks. These unsafe conditions are ignored by involved parties such as project engineers, site engineers, and supervisors.

Omission in unsafe conditions may be caused from ignorance and unawareness of in-charge personnel related to hazards and risks. Occasionally, involved participants, who take responsibilities to arrange safety facilities in construction site, do not have enough experiences and cannot execute safety measures adequately and effectively.

Figure 1. Overviews of actual workplaces and work practice from construction site observation.

To eradicate unsafe conditions and reduce accidents, in-charge personnel should definitely understand and have knowledge associated with the requirements of safety procedures and safety facilities of construction activities performed at high elevation for planning and execution works. It is more effective to allow those personnel gain experiences and knowledge about those activities in the actual construction site. They can perceive inherent potential hazards and risks. However, it is too dangerous to allow construction workers perform in unsafe conditions for educating engineers and supervisors. Thus, an innovative approach is needed to provide visualized information of those activities as they occur in real construction site.

This study aims to develop a visualized approach for simulating the construction activities operated at high elevation using Augmented Reality and to implement this approach for investigating the improvement of construction personnel considerations in safety planning. This approach can educate in-charge personnel regarding safety knowledge. While visualizing the construction activities simulations in the actual site, the construction personnel can understand the construction methods and working conditions of those activities with real surrounding environment. They can consider which factors they must concern when they have to provide the safety facilities for the workers. All of mentioned research objectives are to improve and enhance safety and planning in construction industry.
2 Proposed system architecture

Augmented Reality technology is employed to develop the visualized approach for simulating construction activity performed at high elevation. This technology can supply amount of information through computer graphics and merge the virtual objects into the real world scene (Azuma, 1997). It enables the user perceive, understand and memorize information easier (Wang and Dunston, 2006; Chen and Wang, 2008). The proposed system architecture is configured and shown in Figure 2. The hardware components for developing this system consist of a laptop computer, a video camera, and a HMD.

![Figure 2. Proposed system architecture.]

To develop this system, the following information is required. Current information of selected activity operation at high elevation is necessary. This information consists of implementation of safety measures and temporary facilities, habitual procedures and sequences, safety rules and regulations, potential hazards and risks that are collected and categorized. The information of hazards and risks is used to identify and define the consequences based on previous literatures and experts’ knowledge.

Improvement information is also needed. This information consists of requirements of safety facilities and procedures. These requirements should be implemented to eliminate unsafe conditions. This information is based on the suggestions of in-charge personnel who involve in selected activity operation. Their suggestions are collected by using interview methods. To specify the requirements of safety measures, temporary facilities, and safety procedure, recommendations and assistances of safety experts are needed.

Next, three databases are created in the laptop computer. The first database is virtual model of construction objects which are created into the following four modules: (1) building element module, (2) equipment module, (3) method module, and (4) worker module. The first module contains the building information such as reinforced steel bars and structural elements based on construction drawings of selected activity. In the second module, safety measures such as working platforms, guardrails, and safety nets, and temporary facilities such as scaffolding and formworks are produced. Besides those objects, construction equipment is created as well. The method module is initiated for demonstrating construction sequences and procedures based on temporary facility and safety measure
supply. The last module is worker module which is developed to present virtual worker practices such as their posture and motion when performing activity at high elevation.

The second database consists of the following three contents: (1) hazard database, which collects inhered potential hazards when operating construction activity under unsafe conditions, (2) risk database, which presents likelihood and severity of risks from inherent hazards, and (3) consequence database, which demonstrates the accident situation according to hazards and risks.

The third database is safe and unsafe scenarios for performing construction activity according to the selection of equipment and method. Both safe and unsafe scenarios are classified based on safety rules, regulations, literatures, and experts’ recommendations. In safe scenarios, the appropriate virtual equipment, safety procedures, and virtual work practices are presented via simulation. For unsafe scenarios, not only simulation, but also hazards, risks and consequences of these practices are also illustrated.

A computer program which generates the simulations of construction activity according to safe and unsafe scenarios is developed using Augmented Reality. In order to display and blend the 3D virtual objects into the real world scenes, a special marker is needed and a set of open source libraries for Augmented Reality which is developed by Kato et al. named ARToolkit is employed (HIT LAB, 2009). The simulations are superimposed into the actual construction environment. The visualized simulations imitate real construction tasks both safe and unsafe conditions and present information regarding hazards, risks, and consequences of improper or missing safety facilities while the users perceive actual surrounding environments. The users can visualize and experience similar as they are in the real construction at high elevation situation.

3 Implementation and experiment

The computer program will be implemented to a real construction project as a tool for investigating the improvement of construction personnel considerations. In Figure 2, the user represents to construction personnel. He or she has to wear a HMD which is equipped with a head tracker and a video camera. This HMD is connected to the laptop computer. Head tracker keeps track user’s position and orientation to provide input for the registration computations. Video camera captures the real world scenes and transmits images to the Augmented Reality platform in the laptop computer. The user must look at the marker which is attached in the actual workplace.

In order to perform the construction activity, the user must select construction method and equipment that they can supply. In this proposed system, the user can select construction method, safety measures, and temporary facilities that they can provide to the worker via user interface in the laptop computer. The virtual construction objects which are associated with construction activity and linked with the marker are displayed as a simulation. The virtual simulation demonstrates the construction procedure, selected safety measures and temporary facilities, and worker practices in each construction sequence via a HMD. If the user provides inadequate safety measures or temporary facilities, this system can detect the missing safety equipment or temporary facilities. Then, hazards, risks, and consequences will be explored and presented. The user selection is classified into safe or unsafe scenarios before demonstrating output which is merged with the actual surrounding environment.

Figure 3 presents the dismantlement of column formworks after casting concrete at a real construction site. This operation is located a high-rise building deck of which height is more than sixty meters. The worker climbed to the top of column to screw bolts and he did not wear climbing protection system and lifeline system. Moreover, the temporary facilities such as scaffolding were not provided to protect the worker.

Figure 4 presents superimposed scenes. The system illustrates the virtual building objects, scaffolding, and workers and blends them to the actual construction environment. The in-charge
personnel can visualize the required facilities for dismantling formworks. However, the user must supply another measure which is personal protection system to protect the worker.

For executing experiments, staffs of a high-rise building construction project will be employed to be the sample. They are separated into two groups by random. The first is a control group. In this group, the computer program which can provide safety knowledge in construction activity performed at high elevation will not be executed to the examinees.

The second is a test group. In this group, the computer program will be executed. This group will be tested twice: before and after executing the computer program to measure and to investigate development of their considerations associated with safety facilities and methods in planning. In the experiments, the second group examinees will be placed at high elevation in real construction site, visualized and experienced safe and unsafe construction operation simulations. After finishing the experiments, they will be tested. Considerations of construction personnel will be examined by using test papers. The differences of test results between two groups will be evaluated to investigate their development.
From this proposed system, the construction personnel who take responsibilities in safety facility planning can gain adequate safety knowledge and have a high degree of safety awareness. They are also able to recognize the importance of safety, assign adequate resources to handle it, provide proper considerations during planning to eliminate and reduce safety problems, consider potential safety problems during preparation of method statements, avoid performing unsafe acts, avoid creating unsafe conditions, and identify unsafe acts or conditions and ask for modification.

4 Conclusion

To minimize unsafe conditions and reduce fall accidents in construction, the visualized approach which provides safety knowledge to construction personnel is developed. Safety knowledge must be supplied related to required safety measures and temporary facilities, safety procedures, and work practices. Hazards, risks and consequences which cause from missing to supply required equipments are also provided. It is more effective to enable construction personnel gain knowledge and experience of construction activities operated at high elevation while they are in the real situation. Thus, Augmented Reality technology is employed in this study. This proposed system consists of hardware components, three databases, and a computer program.

This research is in the on-going process and the prototype systems are under development. This system will be executed into the real construction site in order to investigate the development of construction personnel considerations. The participants will be divided into two groups, which are control and test groups, to compare the testing results. The benefit of this study is the improvement of construction personnel in safety and planning. It can enhance construction workers’ health and life quality. Furthermore, it will raise the level of safety in construction industry.

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References