A SMART CRANE OPERATIONS ASSISTANCE SYSTEM USING AUGMENTED REALITY TECHNOLOGY

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ABSTRACT: With the increasing complexity of modern construction projects, maintaining operational safety while increasing the erection speeds of cranes has become an important issue. There are four major problems in current crane operations: (1) dynamically changing working environments, (2) limited viewsfor operators, (3) unclear communication between operators and other crew, and (4) oversimplified control interfaces impeding efficient and safe erections. This research proposes an integrated environment to provide a rich information environment to operators during the erection processes. To achieve the goal, we designed an augmented reality (AR) system with four modules: field information collector, virtual information collector, construction planner, and integrated AR display. Field information is collected by four video cameras and virtual information is collected from the building information model (BIM). Then, the construction planner module processes the information, calculates efficient erection paths and analyzes the possible risks in the erection environment. The results that can be delivered to operators are categorized into two groups: erection progress information and limitation information.. To verify the feasibility of the system, we implemented a control system for theKukarobot arm, which simulates a construction crane. Future work will include the conduct of a user test to verify the usability of the proposed system.

Keywords*: Augmented Reality, Path Planning, Crane Operation, User Interface*

1. INTRODUCTION

Crane operations have a major influence on a construction project, especially in terms of efficiency and safety. At a construction site, many activities rely on crane operations. Cranes not only erect structural components; they also move nonstructural elements. With the growing usage of cranes, the number of crane-related accidents has also grown enormously. The types of crane-related accidents include overturning of cranes, falling of loads, and contact with power lines[1-2]. Any of these accidentsleads toimmense impacts on the safety, efficiency and cost of a construction project. From the analysis of Shapira and Lyachin [3], operator proficiency is the most important factor affecting safety of the construction environment,compared to other operations-related factors such as blind lifts, , operator aids and visibility. Although these factors can have the varying levels of influence, improving the safety and efficiency of crane operations remainsan important issue which cannot be neglected.

Previous studies on cranes provided different kind of improvements which were expected to increase productivity and protect operators from the risk of accidents and injuries. Lee, Kang, and Kim [4] developed a crane which was equipped with wireless video control and RFIDs,to improve the efficiency of lifting objects. Some studies have represented automated path planning systemsto improve the efficiency and the reliability of crane operations [5-6]. Due to improvements in computer graphicsand physics enginetechnology, studies have increasingly experimented with using virtual environments to simulate crane operations. The operator of an actual crane can obtain realistic feedback based on the results of the physics-based simulations' [7].

In recent years, augmented reality (AR) technology has seen rapid development. Augmented reality superimposes 3D virtual models on videos of the real world, in real-time [8]. Augmented reality can also enhance users' visualization and increase comprehension [9], and is an effective aid for the viewer to better understand a 3D environment [10].Many research studies have focusedon the application of augmented reality in the engineering field. Goldparvar-Fard et al. [11] implemented augmented reality into 4D construction models for project management. Schall et al. [12] and used augmented reality to indicate the location of underground infrastructure during an excavation operation. Now that the technology for virtual environments, 3D and 4D models have matured, augmented reality has become a viablesolutionforintegrating virtual reality and the real world [13].

Although simulations can provide feedback to an operator before any action is taken, certain real-life conditions cannot be simulated fully to reflect actual situations. The experience of a crane operator is therefore of paramount importance. Therefore, an operator needs maintain full concentration during the operation. To enhance operators' awareness of all aspects of the situation, an appropriate and effective assistive tool would be extremely helpful and important.

2. RESEARCH GOAL

In this study, we aimed to develop anassistive system for crane operation. With this tool, the operator will have a computer to assist in the operation. Computer screens show live videos of the construction site from different directions, andimportantly, AR videos provide the added information. This tool can increase the efficiency and safety of crane operations. The tool can be efficient based on its clear path, so that the operator can simply follow the path. It can prevent damages by giving warningsto operators. And the tool can also decrease the accident causing by communication mistakes.

3. SYSTEMARCHITECTURE

Theassistive crane operation systemcontains four main modules: (1) field information collector, (2) virtual information collector, (3) construction planner, and (4) AR display.The detailed architecture of the system can be seen in Fig 1.In our architecture, the information collectors provide real-time images and the BIM model of the construction site to the construction planner. As the information is inputted, the construction planner processes and analyzes the information. Finally, the integrated information will be presented on the AR display. The operator can then operate the crane with reference to the enhanced information on AR display.

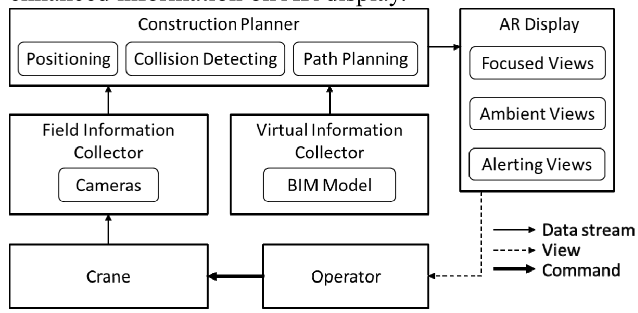


Fig 1The architecture of the operations assistance system.

Field Information Collector

The information collectorprepares information which is required in the construction planner. The input module includes twoparts: camera images and BIM model. The camera images are the scenes of the construction site. When an operator manipulates a crane or other equipment at the construction sites, his/herfield of view is limited, and therefore is unable toperceive the entire whole construction site. Therefore, in this system, we use multiple cameras set at different locations to acquire the images from different directions, so that the operator is able to access more information about the site. The camera images are also used for calculating the featured points in the augmented reality environment.

Virtual Information Collector

In addition to camera images, the BIM model plays an indispensable role in the system.The system we developed requires a virtual environment as a replication of the actual construction site. This is because the planning and material information from the planning stage of construction cyclehave to be utilized, and provided to the operators as a rigging plan for operators. The BIM fulfills this goal. The BIM contains information of building component during its entire life cycle. The virtual models of the BIM provide the various components of the construction site. The models are used for path planning and collision detection in our system. The information of objects being lifted, including their location, size, weight and material, can also be retrieved from BIM. This information is important for the operator during the erection process.

Construction Planner

Theconstruction planneris the main processing unit in the system. Once the information collector transmitsthe information to this unit, the construction planner processes the information, generating the images and other information for presentation on the AR display. Thefunctions of the construction planner include positioning, path planning and collision detection.

Positioning is the core function of the construction planner. In the system, there are two coordinate systems: real world coordinates and coordinates in thevirtual environment. After positioning, virtual information of the ongoing construction plan can be superimposed onto the real-time image. In this research, augmented realityis used to accomplish positioning and matching of these two coordinate systems. Once the positions are determined, informationsimulated in the virtual environment can be provided to the operator.

By understanding the geometrical properties, the second function of construction planner, path planning,,generates a collision-free path anda virtual path model, based on the coordinates of the virtual environment that have already been rectified with that of the real world. The displays can thus show both the views of the construction site and the path model. The operator can adjust the operation according to the recommended path shown on the displays.

In the system, we also developed a collision detection mechanism. During the operation, it is dangerous for any lifting objects to collide with any other components in the construction site. Any such accidents are likely to lead to serious fatalities and injuries. Therefore, in order to prevent any collisions, a safe distance is set.If the distance between two objects is smaller than the safe distance, the system will send a warning signal to the operator.

AR display

The AR displayintegrates and presents the enhanced information to the operator. The operator would then rely on the displayed informationto manipulate the crane. Information such as recommended path, collision warning signal, and loading capacity of the crane has differentpriorities in an operation. We have also considered varying attention levels of human beings in our design, so that the operator will be able to perceive the presented information effectively. Different display methods are adopted for different types of information of different priorities. The AR display of the system has three types of views: focused views, ambient views, and alert views. The details of these views are described in the next section.

4. INTERFACE AND VIEWS

In the system, information from construction planneristransmitted to theAR displaywhich is presented to the operator. In this research, we also focused on adopting effective information display techniques to provide the operator with better situational awareness. We divided the information of a rigging task into two categories, and their respective information is divided into different views in the system interface. Also, with different priorities,the information is presented in different ways.

As the Table 1 shows, the two main categories areerection progress and limitation. The information of first category would help operators to complete the erection tasks safely, accurately and effectively. The information includes lifting information, path, communication, crane attitudes and site scene. However, the information in the second category would limit or interrupt dangerous erection tasks or pathways. This category of information is concerned with safety issues. The information includes working range of the crane, weight of the object, collision, human presence, and weather. This information on limitations has a part to play in controlling the risk of accidents or injuries occurring. Therefore, methods for displaying the information effectively are also a key part of this research.

Table 1 shows the categories of information required in a rigging task. It also organizes the information by views and their priorities based on different levels of attention.

Matthews et al. [14] summarized previous research and developed the curve of awareness and attention. There are four zone of attention: preattention, inattention, divided attention, and focused attention. In our system, we separate views based on divided attention and focused attention. Focused attention refers to how a person would attend to, or concentrate only on one stimulus. Divided attention would refer to how a person would distribute his/her attention across several things simultaneously.

Table 1 List of the attention items and display methods

Categories	Items	Description	Views
Erection Progress	Lifting information	Lifting information includes the objects' name, ID, size, shape, etc.	Ambient
	Path	The operator has to consider the trajectory for moving the rigging object to the destination.	Focused
	Crane attitudes	Crane attitudes used to show the angle, direction, or length of the jib, cable, and hook.	Ambient
	Communication	The operator has to communicate with other workers or comprehend their instructions using hand signals.	Focused
	Site scene	The scene of the construction site.	Focused
Limitation	Working range of the crane	The capacity of the crane when the objects are being lifted at different positions. The lifting moment may be at over-capacity and cause the crane to overturn.	Alert
	Weight of the object	The weight of lifted object must within the maximum crane loading capacity.	Alert
	Collision (excluding human)	Operator should notice any obstacles on the lifting path and any potential collisions that might occur.	Alert
	Human	If there is any person in the working area of the crane, the operator will have to pay close attention.	Alert
	Weather	Weather phenomena which could affect the risk-level of the operation, such as wind speed and occurrence of rain.	Ambient

As Fig 2 shows, the AR display of the system has three types of views. The first comprises focused views, in which the information would be constantly displayed. The operator would therefore pay more attention to this view. Therefore, this view is positioned at the center of the operators' overall view, and is also the largest. The second view is the ambient view. Information from this view would show up on the surroundingof the screen but the operators will be able to find them easily when required. The third view is the alertview. The alert view is used to display information related to safety. The view would provide distinctive signals to shift the operator's attention from the original task, when the risk of accidents occurring is high. For example, if the lifted object is too close to the building element, the system would display a signal to attract the operator's attention, enabling the operator to make adjustments to prevent any potential collisions. The alert view is able to display three levels of urgency. The signal would show current data when the operation is within the safe range. When there are potentially unsafe situations, the background color of the information would change to yellow to remind the operator to operate with caution. If the color turns red, it means that the situation is dangerous and the operation must stop. There is also information overlain on the screen to shift the operators' attention. This alert system would enable the situation would be fixed in time, before any accidents occur.

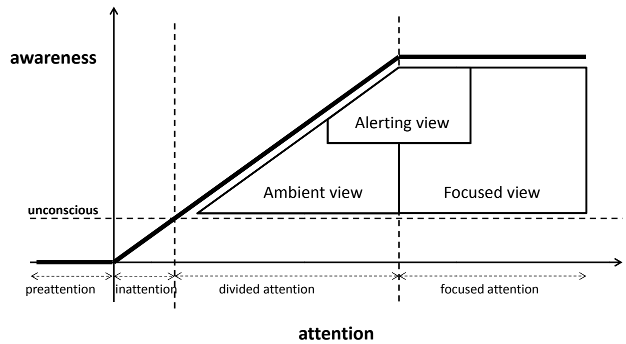


Fig 2 Relationship between views and attention (modified from Matthews et al. [14])

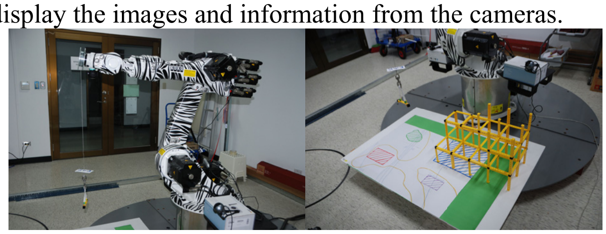
5.SIMULATED ENVIRONMENT

In this research, weused an industrial robot arm, KUKA KR 16 CR, to simulate cranes, as shown in

Fig 3 (a). An arm-like crane was developed by adding a cable with a hook in the end-effector of the robot arm. The arm-like crane is able to move and lift objects like an actual general crane. The work area in which the robot arm operates is a simulated construction site.

To provide views of the construction site, fourwebcamswere set up. The threewebcamswere at the top of the crane's cable right-side and left-side of the crane, withanother far from the site to monitor the global situation. As shown in Fig 3 (b), plastic components were used to simulate the steel structures in the simulated site.

For system processing, a PC running Windows 7 (3.2 GHz 8-Core Intel Xeon with two nVIDIAGeforce 8800GT graphics cards and 2GB RAM) was set up to receive data and process the system information. In addition, the computer was equipped with two 24" LCD monitors to display the images and information from the cameras.



(a) (b)

Fig 3 (a)Arm-like crane (b) Simulated construction site

6. INTERFACE DEMONSTRATION

An operator would operate the crane with four screens. As show in Fig 4, the screens on the top show the ambient views and the bottom screens show the focused views. The operator could follow the given collision-free path to move the object.

Fig 4 Interface of the system

The operator would concentrate on the operation by watching the focused view. The alert view would help to detect dangers and provide signals if any hazards appear. For example, during the operation, when the lifted object came too close to the original structure, the background color of the collision information would change to yellow. If the object was moved even closer, the color would change to red and a signal would also be displayed on the focused view.

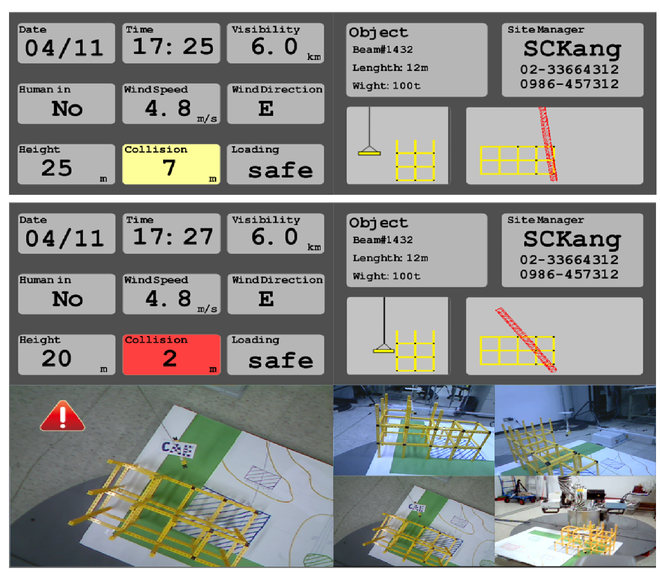


Fig 5 Interface of alert view.

7. CONCLUSION AND FUTURE WORK

In this study, we developedan AR crane operations assistance system to increase operational efficiency and safety. This system uses augmented reality to combine images of the real worldwith virtual models. Thesystem also integrates path planning and collision detection functions. The path and the simulation developed by the system can be continually referenced by the operator during the operation. We also divided different types of information, such as recommended path and warning signals, into three views based on current understandings about the human attention zone. By using different display methods for the three views, we demonstrated the system and the environment was likely to enable the operator receive the information effectively. However, the simulation performed in the simulated environment still has some limitations.

Further research willinvolveusability tests to gather feedback and opinions about the system. Also, the AR crane assistance operation system will improve in two directions: increase the stability of the augmented reality or positioning method to enable more instructions to be added,and gathering of more feedback to further improve the user interface. Finally, further investigations are required to ascertainthe performance of the AR crane assistance operation systemby implementing it in an actual construction site.

8. ACKNOWLEDGEMENT

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