RADIO FREQUENCY TECHNOLOGY INCORPORATED APPROACHES TO EQUIPMENT COLLISIONS ON JOBSITES

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Abstract: This paper discusses a framework for preventing equipment collisions. The framework is built upon the understanding of the patterns of equipment moves and strategies for real-time assessment of potential collisions that are results of a study conducted as part of this research initiative. It consists of three components—real-time data collection platform, a visualization module, and a decision module. It involves ultra-wideband technology for precision tracking of equipment position in real-time. A prototype system is developed to test the technical feasibility of the framework and the incorporated technology. T-type tower crane is used as an exemplary case in the development of the prototype system. To test the feasibility of the framework, this study conducted experiments using two tower crane models in a lab environment similar to that of a cluttered jobsite. The system continuously measures distances between equipment and issues a warning in case of potential collisions. By doing so, it makes crane operators recognize dangerous situation in time. The results of this study show that integrating precision tracking technology and real-time data analysis method can produce capable tools for enhancing equipment safety on the jobsites.

Keywords: *Equipment Safety, Collision, Tower Cranes, Automated Real-Time Monitoring, Ultra Wideband*

1. INTRODUCTION

Equipment collisions on site can cause project stakeholders tremendous consequences—fatal injuries and deaths to workers, higher insurance premiums for contractors, and delays to owners' occupancy of completed projects. Its influence often reaches even to the public which is not directly involved in a project by incurring damages to existing facilities and presenting interruptions to traffic using roads near the project. Safe use of construction equipment, therefore, is essential to successful delivery of a construction project.

The goal of this research initiative is to enhance construction safety by preventing heavy construction equipment from colliding with each other on the jobsites. The lack of timely recognition of dangerous situations has been known to be a primary cause of equipment collision (Pratt 2001; Fullerton et al. 2009). Despite the known cause, equipment operators in general are not able to pay full attention to other equipment in close proximity while engaged in construction processes.

Such situations pronounce a need for technical solutions that can assist equipment operators in monitoring and assessing potential collision more safely and proactively. Recognizing the need, a study that is conducted as part of this research initiative has evaluated a few potential technologies. Each technology was compared based on a few capacity-related criteria—line-of-sight, cost, reliability, response time, and operation range—that can affect the efficiency of real-time tracking of equipment, the assessment of potential collision, and following decisions for collision prevention. As a result of the study, ultra-wideband (UWB), a radio frequency technology, was selected for its superiority in those capacity criteria. This study envisions that integrating UWB and real-time data analysis can produce a capable method to reduce costly accidents of equipment collision.

This paper presents the results of an experimental study. The purpose of the study is to investigate the feasibility of a proposed collision-prevention strategy for monitoring and assessing potential collisions of equipment that makes "axial-rotation"—which is defined as a pattern of move that rotates around a fixed axis. In this study, the collision-prevention strategy is applied to tower crane—a typical type of equipment that makes "axial-rotation." The equipment was selected, considering its essential services for construction processes and its great impact on construction safety in the event of a failure.

In this context, the present study developed a framework by applying the strategy, which was followed by the development of a prototype system. It should be noted that comparison of the prototype system with other existing systems involving different technologies is not the interest of the present study. Rather, it focuses on the examination of the technical feasibility of the developed framework and the applied UWB technology for preventing collisions between pieces of equipment on site.

In line with the objective, the present study conducted the following tasks: (1) develop a framework for monitoring and assessing potential collision of tower crane in real-time; (2) create a prototype system based on the framework, incorporating UWB technology; and (3) conduct experiments to evaluate technical feasibility of the framework and the technology.

2. SAFETY OF TOWER CRANE OPERATION

Currently, the efficiency and safety of tower crane operation primarily depends on the human cognitive ability. Tower cranes are normally operated by a team of an operator, a rigger, and a signalman. The team heavily relies on intuitive perception of the positions of objects, either in stationary mode or in motion mode, as they plan moving paths. This requires them to be vigilant and attentive to various objects while operating a crane. However, it is difficult for operators in particular to be highly attentive all the time, because they also have to support complicated construction operations, such as steel erection, curtain wall installation, etc. In addition, many projects use multiple cranes simultaneously on the jobsite, which adds more difficulty to operators and increases risk of crane-to-crane collision.

Under the circumstances, tower cranes have been known to be one of primary causes of fatalities on the construction jobsites (US Department of Labor 2008)—furthermore, 81% of the fatalities related to crane accidents are potentially attributed to collision of cranes (Neitzel et al. 2001). In particular, the collapse of a crane, which is one of the consequences of crane collision, can injure people and cause damage to vehicles and even to existing facilities both on and near the jobsites. Accordingly, protecting construction workers and the public from crane-involved accidents has been of a keen interest of the construction industry (US Department of Labor 2008).

Collisions between cranes essentially occur when parts belong to different cranes contact each other. The contact can happen between booms, between a boom and a mast, and between a boom and a hoisting cable. Therefore, it is necessary to continuously track and locate the positions of parts of cranes for collision-free operations of cranes. Furthermore, the assessment of the possibility of collision needs to be made in real-time, so that crane operators can take preventive actions in time.

Fig. 1 Two T-type tower crane models for experiment

3. RESEARCH METHODOLOGY

The primary research methodology of this study is experiment—an effective way to test technical feasibility of new developments in a safe environment. T-type crane is selected in the present study, considering relatively widespread use in construction. Upon the selection, a preliminary study was conducted to understand the structural and mechanical characteristics of the crane.

The results of the preliminary study were used to create two models for experiments (Fig. 1). Each model consists of a base, a 4-foot-tall mast, a 7-foot-long boom (horizontal jib), a cable (lifting wire rope), and a hook. All of these parts, except for the cables are made of steel to maintain the characteristics of materials used for real cranes.

As the models are completed, a few preliminary experiments were conducted in a lab space (40ft x 40ft) using the models and the incorporated UWB, which were conducted to obtain fundamental knowledge for the development of a framework for real-time prevention of tower crane collision. The lab, like a real construction site, is filled with various objects, including steel gas tanks, wood materials, bricks, metal cans, and plastics. Four UWB sensors (receivers) were installed at four corners in the lab, and two tags were mounted on the boom of each crane model. Following the analysis of preliminary experiments, a framework was developed. The framework, along with the incorporated UWB technology, provides the foundation of a prototype system that is also created in this study. Additional experiments were conducted by implementing the prototype system to verify and validate the framework.

4. A FRAMEWORK FOR REAL-TIME PREVENTION OF TOWER CRANE COLLISION

The developed framework consists of a data collection platform, a visualization module, and a decision module.

4.1 Real-Time Data Collection Platform

A platform is needed to collect spatial data—the physical positions of objects of interest. Such a platform is normally provided by technology product vendors, which is also true for the present study. The applied UWB technology locates tags attached to crane models and measures the position of each tag in space. Signals from the tags are detected by sensors and are fed into a platform. The platform converts the signals into 2- or 3-dimensional coordinates. In this study, tags were configured to emit signals four times per second. Accordingly, the entire process is repeated four times per second, which allows nearly real-time monitoring.

4.2 Visualization Module

The visualization module reads in the coordinates at the same interval of detection of signals; in other words, the converted coordinates are retrieved by the visualization module in real-time. A mapping algorithm in this module processes the coordinates to represent the booms of cranes. The algorithm maps the coordinates on to an *x*-*y* plane to show relative positions of the booms as illustrated in Fig. 2. For this, the algorithm pairs up two coordinates that represent the positions of two tags attached to the same boom and draw a straight line between the coordinates. This allows a boom to be realistically illustrated in linear shape instead of points, which makes it easy to tell the relative position of each boom on a plane. The simple approach enables an operator to check the position of his or her crane's boom and those of other cranes in close proximity.

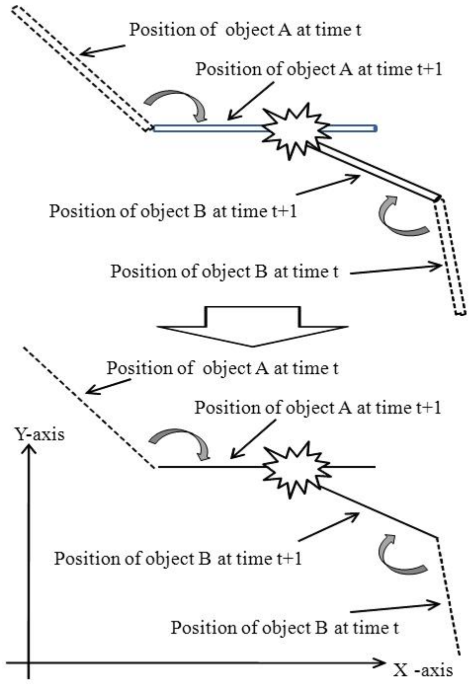

Fig. 2 Mapping and visualization of crane position

Note that the third dimension for height is excluded for the following reason. When the booms overlap on a 2-dimensional plane, then the booms collide regardless of the heights of the booms: if the heights are the same, then the booms collide with each other; and if the heights are different, then a boom with a lower height collide the cable of a crane with a higher height.

4.3 Decision Module

The decision module consists of a set of rules and algorithms for assessing the possibility of collision. The visualization module only shows the positions of booms graphically; it cannot determine if two cranes are at risk of collision. In order to determine whether the cranes are about to collide, the shortest distance (d_t) between booms needs to be measured all the time (Fig. 3). In the applications of sensor technologies, such a distance is normally measured by using the coordinates representing the positions of tags attached to booms. However, there is a problem with applying these coordinates directly, because the distance between two tags can be longer than the true shortest distance between booms. In other words, the actual distance between two cranes can be shorter than the distance between two tags adjacent as depicted in Fig. 3. A method is developed to solve the problem as shown in Fig. 3. It is assumed that the minimum allowable distance—a so-called safety distance (d_s)—between booms at any time is predetermined as a condition of safety. Given the predetermined value of d_s, it is possible to find what the distance between two tags (d_{bt}), corresponding to the safety distance, would be. d_{bt} can be calculated using a site layout CAD drawing that shows the positions of cranes and monitored in real-time by detecting the positions of tags. As cranes are operating, the module continually measures d_{bt}, instead of d_t, at the same interval of spatial data collection.

The decision module uses the measured distance d_{bt} to assess the possibility of collision between cranes. The distance is tied with a set of rules for decision-making—for instance, if d_{bt} is shorter than or equal to 2m, then the module issues a warning to operators. In assessing the possibility of collision, the predetermined distance d_s becomes a threshold parameter value which defines the minimum distance between booms required to prevent collision. Accordingly, the parameter value of d_{bt} for a given d_s can be thought of as a predetermined threshold value.

In order to track d_{bt}, it is necessary to pair up two tags as shown in Fig. 4. It, however, is not required to monitor the distance between two tags mounted on the same crane, because they are on the same boom. Again, the tags are attached to booms, because collision between T-type cranes always involves at least one boom. As explained earlier, collision between a boom and a hoisting cable can be detected by tracking tags on the booms. By measuring the actual distances for the pairs of two tags, the decision module determines a situation to be unsafe when any of the actual distances is shorter than or equal to the predetermined threshold value of d_{bt}, corresponding to d_s, for the pair. Once a warning has been activated, the operator is expected to take recommended action, such as slowing down, stopping, or checking.

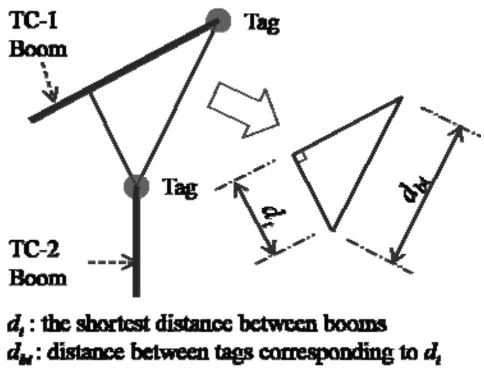

Fig. 3 Method of calculation of the shortest distance

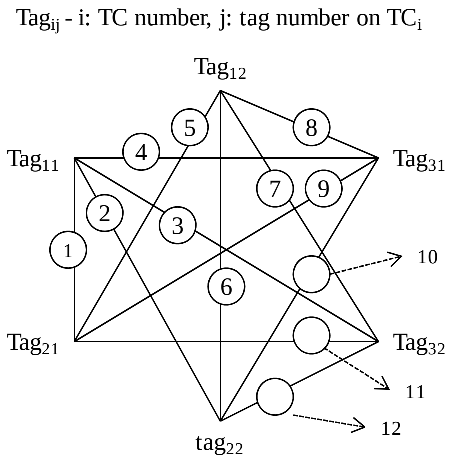

Fig. 4 Pairing tags for monitoring the parameter, d_{bt}

5. A PROTOTYPE SYSTEM

In order to validate the framework, a prototype system was developed and tested via experiments. The following describes a few important features of the developed prototype system. The system consists of two primary functions—setting safety distances (Fig. 5) and real-time monitoring and warning (Fig. 6).

The system is designed to allow monitoring up to three cranes at the same time. While it is possible to increase the number of cranes, it is unusual to install more than three cranes in close proximity at the same time. Given a predetermined safety distance—the allowed shortest distance (d_s) between two cranes in close proximity—users can enter the distances between two tags (d_{bt}) using the window shown in Fig. 5. Depending on the position of rotational axis, which is the same as the position of mast, the parameter value of d_{bt} for each paired tags can be different. The number of pairs of two tags grows as the number of cranes increases. There are four possible pairs with two cranes and 12 pairs with three cranes (Fig. 4).

The system starts monitoring as cranes begin to move and continuously tracks the position of each boom over time. The system retrieves 2-dimensional coordinates (x, y) of each tag from a central hub that receives and converts signals into coordinates. The visualization module of the system processes the retrieved coordinates to generate a line by connecting two coordinates. The module shows the lines in a graphical user interface window (Fig. 6). All of these manipulations occur in real-time.

Fig. 6 presents a situation of potential collision. In this experiment, two cranes are monitored. When two cranes come too close to each other, the distance between the two cranes keeps decreasing and eventually reaches the safety distance. The decision module of the system measures the current distance between booms by reading coordinates of the paired tags and compares it with the predetermined parameter value d_{bt} for the pair in real-time. If any one of the measured current distances becomes shorter than or equal to its corresponding d_{bt}, the system issues a warning message blinking until the dangerous situation is resolved. Fig. 6 also shows a message which is issued when one of the actual distances between the paired tags becomes shorter than or equal to 0.3m—a predetermined distance between two tags.

It is not unusual for operators engaged in a complicated construction process to miss the warning message; in that case, an audible warning can be more effective. Thus, the warning sound is accompanied with a blinking warning message—both ways complement each other. The system has been tested over and over by changing approaching directions of the booms and the approaching speed. Each time it successfully measured all distances and reliably assessed the possibility of collision.

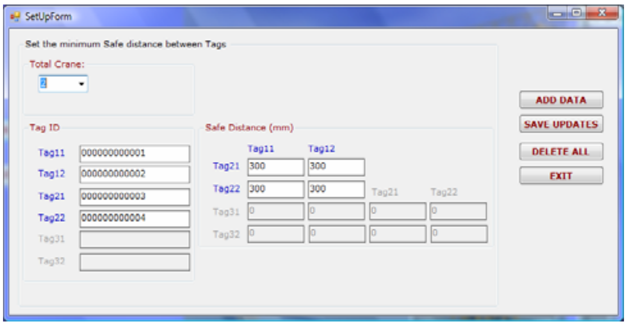

Fig. 5 Input of predetermined safety distances

6. CONCLUSIONS AND DISCUSSIONS

In this study, a framework for monitoring and assessing potential collision of tower cranes was developed by applying a collision-prevention strategy for equipment that makes "axial-rotation" move. The framework was validated by means of experimental tests of a prototype system that was created based on the framework. The results of experiments with T-type tower cranes show that the framework is technically feasible—it effectively utilizes sensed signals to measure relative positions between cranes, to determine dangerous situations, and to alert operators in a proactive manner. The experiments also reveal that the incorporated UWB technology can be successfully applied to monitor and control equipment operations. Its application can be significantly extended beyond simple locating task—the technology is expected to bring a meaningful advancement to monitoring and controlling construction safety on the jobsite.

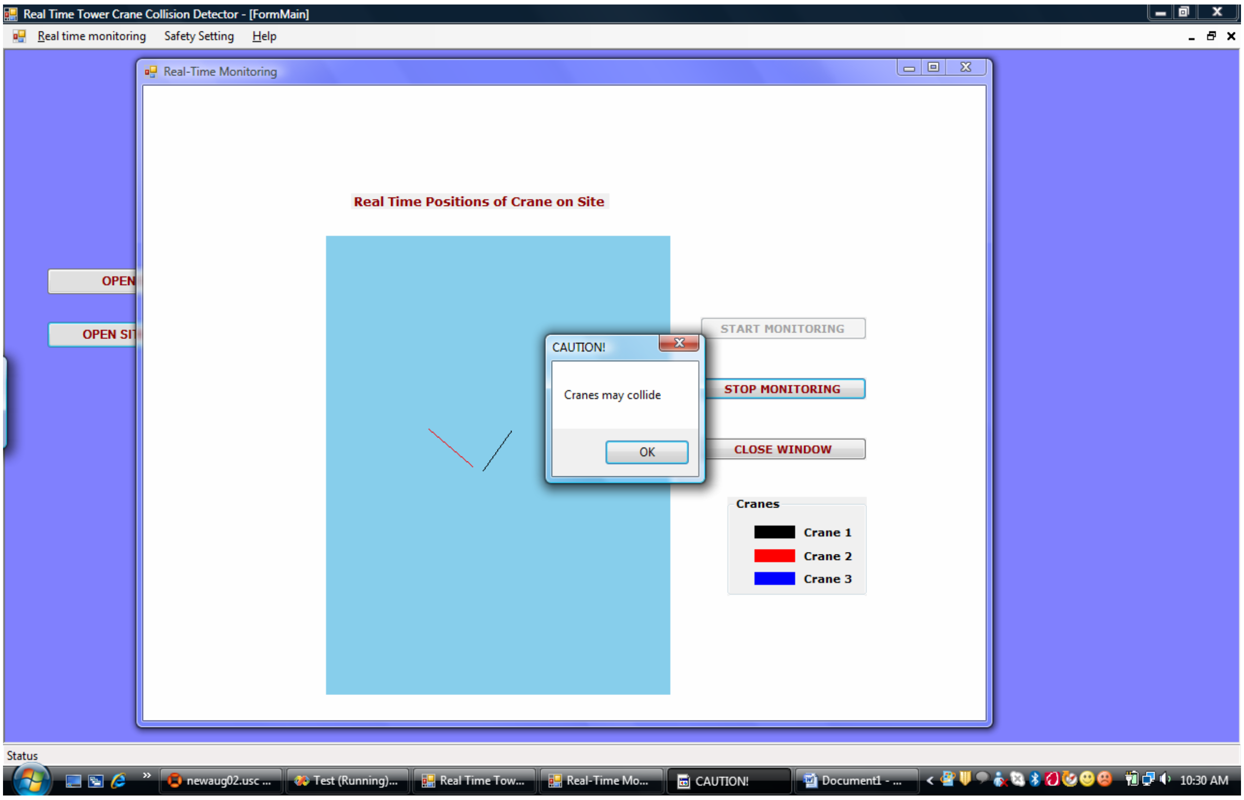

Fig. 6 A warning, both audible and graphical, is issued to alert crane operators.

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