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Advance Crane Lifting Safety through Real-time Crane Motion Monitoring and Visualization

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Abstract: Monitoring crane motion in real time is the first step to identifying and mitigating crane-related hazards on construction sites. However, no accurate and reliable crane motion capturing technique is available to serve this purpose. The objective of this research is to explore a method for real-time crane motion capturing and investigate an approach for assisting hazard detection. To achieve this goal, this research employed various techniques including: 1) a sensor-based method that accurately, reliably, and comprehensively captures crane motions in real-time; 2) computationally efficient algorithms for fusing and processing sensing data (e.g., distance, angle, acceleration) from different types of sensors; 3) an approach that integrates crane motion data with known as-is environment data to detect hazards associated with lifting tasks; and 4) a strategy that effectively presents crane operator with crane motion information and warn them with potential hazards. A prototype system was developed and tested on a real crane in a field environment. The results show that the system is able to continuously and accurately monitor crane motion in real-time.

Keywords: Crane motion monitoring, visualization, real-time, sensors

I. INTRODUCTION

Cranes are one of the most expensive and frequently used types of heavy equipment on construction sites. They are extensively used in most lifting activities and usually have a huge workspace covering most site areas. However, due to the importance of cranes on construction activities, crane-related accidents could result in catastrophic consequences, such as injuries and fatalities. From 1992 to 2006, crane-related accidents in the United States led to 632 worker deaths, an average of 43 deaths per year [1]. During a crane lifting operation, the crane operator has the most direct influence on the operation safety; however, many studies and historical statistics reveals that operator failures are the major reasons lead to crane-related accidents. In practice, safe and efficient crane lifting execution relies heavily, if not solely, on the crane operator's skill and experience. Both issues could be jeopardized by operator failure such as poor situational awareness and inattention caused by distraction or fatigue. Although operator failure has been identified as a major contributor to crane-related accidents, few practical tool are available to effectively assist crane operators to safely and efficiently execute their lifting tasks. One of the major obstacles in developing such tool is accurately and reliably capturing crane motion in real-time and effectively present the data to the crane operators.

The objective of this research is to explore an accurate and reliable method for real-time crane motion capturing and investigate an effective approach for assisting hazard detection and decision making. This paper presents the framework and a prototype of a real-time crane motion monitoring and visualization system. Section 2 introduces previous research related to crane motion monitoring and visualization. Section 3 and 4 present the methodology and development of the proposed system. Section 5 shows the preliminary results of the implementation of the developed system a field test. Section 6 concludes the findings in this study and envision the future work in this direction.

II. RELATED WORK

Much research has focused on capturing crane motions in real-time, and different approaches have been investigated to achieve this goal. Most commonly used technologies in these attempts are tracking-based, laser-based, and camera-based techniques. Zhang et al. (2011) employed a tracking technology called Ultra-wide band (UWB) to estimate the crane pose in near real-time [2]. In this system, UWB readers are deployed around the lifting scene and UWB tags are mounted on different spots of crane boom and the lifted object. However, the system failed to track the load position because the tags on the crane load cannot be detected continuously due to serious signal loss, which is a common limitation of UWB technology. Lee et al. (2009) developed a laser technology based robotic crane system to improve the crane lifting productivity [3]. In this system, the laser-sensor, installed at the tip of the luffing boom, measures the vertical distance of a lifted object using a laser beam reflected from the reflection board installed on the hook block. Shapira et al. (2008) developed a vision system for tower cranes to increase the operators' visibility to the load during loading and unloading [4]. As another attempt to towards this direction, Lee et al. (2012) introduced an anti-collision system for tower cranes which employs video camera and other sensors to monitor crane motions and check potential collision with surrounding objects [5]. Although these efforts can potentially improve operators' visibility and situational awareness, their flaws such as low accuracy and poor reliability greatly limit their effectiveness in assisting hazard detection and decision making.

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III. METHODOLOGY

The major effort in this research is to 1) develop a system framework that enable accurate and reliable motion monitoring for crane operation, and 2) design an approach for visualizing the crane motion information to the crane operator. To achieve these goals, this study proposes a system framework that consists of three sub-systems: 1) crane motion monitoring system, 2) visualization system, and 3) onboard display and warning system. Figure 1 shows the framework of real-time crane motion monitoring and visualization system.

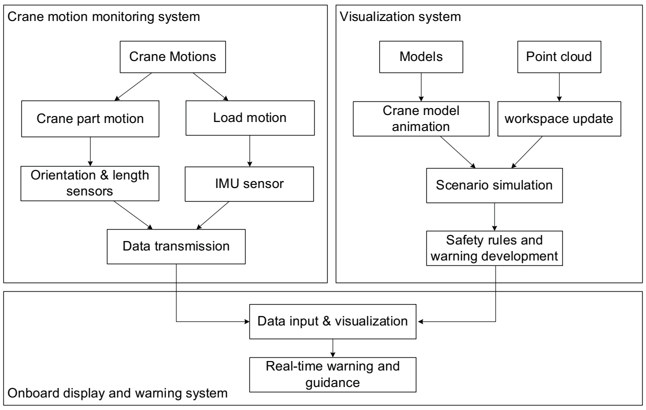

Figure 1: Framework of real-time crane motion monitoring and visualization system

The crane motion monitoring system captures crane parts and load motion in real-time through different types of sensors including encoder sensors for measuring orientation and length data of crane parts, and inertia measurement unit (IMU) sensors for measuring linear and angular acceleration of crane load [6]. The visualization system involves modelling crane parts and update workspace environment data through laser scanned point cloud. Once the lifting scenario is simulated, particular safety rules in the operation can be introduced by proximity limits. The on-board display and warning system receives the motion data collected by the crane motion monitoring system and visualize the crane motion in the virtual environment developed in the visualization system. The on-board display and warning system provides clear view and effective warning while keeps minimum distraction to the operator.

As shown in Figure 2, the developed prototype of the crane motion capturing system consists of five sensors and an on-board display system. Boom lifting angle is measured by an orientation sensor installed in the middle of the main boom section. Boom extension is obtained by measuring the distance from the sensor to the top of the third boom section. Crane slew angle is measured by an encoder sensor by attaching a small gear to the main crane gear. Cable length is measured by an encoder sensor as the crane cable rim spins. The on-board display system consists of a Microsoft Surface laptop, an adjustable laptop holder, and a 3D mouse.

Figure 2: System configuration and sensor setup

Figure 3 shows the user interface of the on-board display and warning system presents the operator with information including 1) three angles of view to the virtual lifting scenario (i.e., top view, elevation view, and a free flying view controlled by the 3D mouse), 2) visual and vocal warning when safety rule is violated.

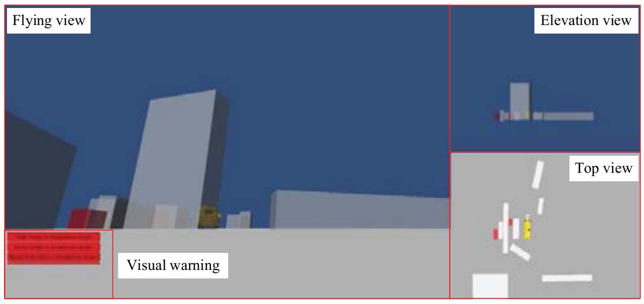

Figure 3: User interface of the on-board display and warning system

IV. FIELD TEST

The crane motion monitoring and visualization system was installed on a 70 ton telescopic mobile crane. The system was tested on a crane yard with various types of objects serving as obstructions. The performance of the prototype system was tested and evaluated in a simulated blind lift scenario. In this blind lift scenario, a metal plate on a truck trailer needed to be relocated to a temporary storage place. Sitting between the trailer and storage were two spare lattice booms and a pile of crane counter-weight .These obstacles blocked the direct line of sight from the operator to the load at the beginning and the end of the lift job. The red boxes shown in Figure 4 indicate the pickup and place locations and the yellow boxes represent the spare crane boom as obstacles in the blind lift scenario.

Typically in such blind lift scenario, the operator need to total reply on a signal person who guides the crane operation. In our test, the signal person is replaced by the proposed crane motion monitoring and visualization system.

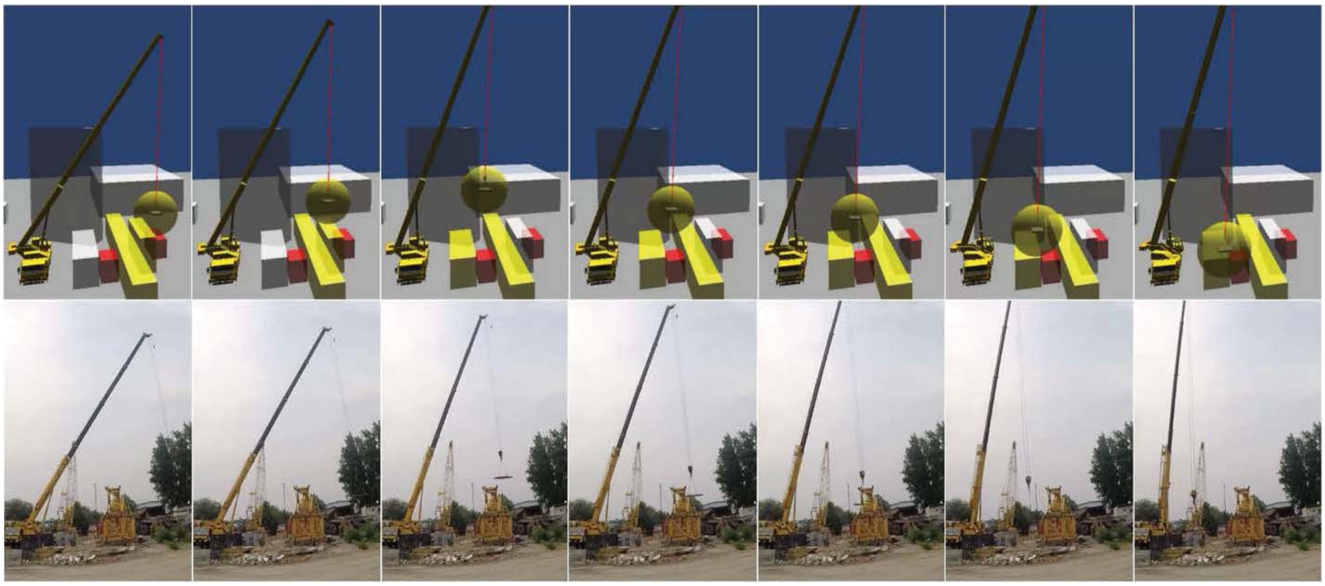

Figure 4: Comparison between virtually visualized crane motion and real crane motion in a blind lifting operation

Figure 4 shows the comparison between virtually visualized crane motion and real crane motion in the blind lifting operation. The test results indicate that the developed prototype system is able to accurately and continuously monitoring the crane parts and crane load motion in real-time.

V. CONCLUSIONS

This paper presents an automated approach that accurately and reliably monitors crane motions in real-time through fusing and processing data (e.g., distance, angle, acceleration) from different types of sensors. Furthermore, a prototype of the proposed system was developed and tested on a real mobile crane. The system performance during a simulated blind lifting operation indicates that the developed system is able to accurately and continuously monitor the crane motion in real-time, and the visualization system can effectively present the virtual crane motion to the crane operator.

The proposed approach for monitoring crane motion will help understand crane lifting characteristics, identify inherent hazards in lifting tasks, and most importantly reduce fatalities in the construction industry. Future research towards this direction will improve overall crane lifting safety, inspire similar applications on various types of construction equipment, and advance the general automation process in construction industry.

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