P3-5

TRACKING LIFT-PATHS OF A ROBOTIC TOWERCRANE WITH ENCODER SENSORS

Suyeul Park[1], Ghang Lee[2], Joonbeom cho[1], Sungil Hham[1], Ahram Han[1], Taekwan Lee[1]

[1]Research Assistant, Yonsei University, Seoul, Korea
[2]Assistant Professor, Yonsei University, Seoul, Korea
Correspond to Ghang Lee at glee@yonsei.ac.kr

ABSTRACT: This paper presents a robotic tower-crane system using encoder and gyroscope sensors as path tracking devices. Tower crane work is often associated with falling accidents and industrial disasters. Such problems often incur a loss of time and money for the contractor. For this reason, many studies have been done on an automatic tower crane. As a part of 5-year 23-million-dollar research project in Korea, we are developing a robotic tower crane which aims to improve the safety level and productivity. We selected a luffing tower crane, which is commonly used in urban construction projects today, as a platform for the robotic tower crane system. This system comprises two modules: the automated path planning module and the path tracking module. The automated path planning system uses the 3D Cartesian coordinates. When the robotic tower crane lifts construction material, the algorithm creates a line, which represents a lifting path, in virtual space. This algorithm seeks and generates the best route to lift construction material while avoiding known obstacles from real construction site. The path tracking system detects the location of a lifted material in terms of the 3D coordinate values using various types of sensors including adopts encoder and gyroscope sensors. We are testing various sensors as a candidate for the path tracking device. This specific study focuses on how to employ encoder and gyroscope sensors in the robotic crane These sensors measure a movement and rotary motion of the robotic tower crane. Finally, the movement of the robotic tower crane is displayed in a virtual space that synthesizes the data from two modules: the automatically planned path and the tracked paths. We are currently field-testing the feasibility of the proposed system using an actual tower crane. In the next step, the robotic tower crane will be applied to actual construction sites with a following analysis of the crane's productivity in order to ascertain its economic efficiency.

Keywords: tower crane, encoder sensor, path tracking system.

1. INTRODUCTION

As robot technologies develop and demands for ultra high buildings increase, interests in the automation of weight lifting works are being enhanced. Studies made by now have applied the element technologies of robots to weight lifting equipment thereby improving work processes and complementing construction machine technologies and though these processes, automation of construction is progressing. In building up skyscrapers, tower cranes are being used in major processes doing many works. However, the tower cranes used in construction sites have problems in that their monthly rents are high and that they frequently cause accidents due to excessive works performed by constructors in order to shorten construction periods. The effect of the skill of tower crane operators on weight lifting works and entire construction periods is classified into a large risk in terms of work management. To solve this problem, preceding studies have been focused on safety, efficiency and productivity. This study mainly describes the research outcomes of produced in the course of implementing the task 「development of robotic crane based automated systems to build up high-rise building structures」 ordered by the Ministry of Land, Transport and Marine Affairs which is a Korean governmental organization as a part of the plan to automate construction machines for the development of construction technologies. Currently, this study task is in the process of the 3rd year out of the study period of 4 years and 10 months in total and the research & development fund of 22.6 billion won in total was invested into 24 organizations that took in charge of individual sub divided study subjects thereby developing automated systems to build up the structures of high-rise buildings. This paper is about the content of 4-2 detailed task for Yonse University「development of intelligence type weight lifting control systems using combined RFID technologies」 which is a research into the development of robotic crane systems for automatic weight lifting by tower cranes. The robotic crane system consists of a lift path creation system, a lift path tracking system and a lift control device that connects the two systems with each other. The lift path tracking system monitors the material being lifted at real times to see if it goes out of the planned lift path and the lift control system enables to create a new path when the material being lifted has gone out of the lift path. This study is to test if lift paths can be tracked especially using Encoder Sensors. Through existing studies, the applicability of laser sensors and GPS has been confirmed but each of them has strengths and weaknesses. Laser sensors are highly accurate but have the weakness that they are sensitive to shaking of the material being lifted etc. GPS is characterized by easy measurements but has a problem that the error rates are large. This study is purposed to apply encoder sensors to tower cranes in order to measure horizontal distances and verify the accuracy of sensor equipment.

1.1 Scope of the study and the method

To track the lifting locations of tower cranes, this study used the research method as follows. First, this study analyzed papers on the automation of tower cranes and then suggested methods to apply sensor technologies based on existing lifting processes. The scenario of the tower crane lift tracking system has been designed based on the installation of encoder sensors in tower cranes in order to enable measuring vertical lifting distances. And to more accurately analyze the measurements of distances of tower cranes, encoder sensor prototypes were installed in a 40m high T type tower crane for testing and the result was analyzed through statistical methods.

2. PRECEDING STUDIES

Domestic studies on automated construction began from the theoretical study performed to selected works to be automated suggested by Korea Institute of Construction Technology (KICT) in early 1980s. Lee, Jeong Ho et al. [1] applied GPS (Global Positioning System) and Machine Vision technologies to tower cranes to study on the method to improve work efficiency. Also, to improve the efficiency and stability of tower crane lifting works, they collected information with GPS receivers and thereby expressed accurate information values on a 2-dimensional plane and then suggested a plan to improve lifting processes. Also, Yun, Seok Hyeon et al. [2] developed a BIM based tower crane object model using Autodesk Revit and they performed location tracking tests using two GPS sensors. Also, in a tower crane simulation system, they suggested a study to measure compensated GPS locations and deliver the measured values as the attribute values of the tower crane object model through Autodesk Revit SDK thereby moving the tower crane to the measured location in BIM environments. As a study in a foreign country, Rosenfeld et al. [3] applied a half automated navigation system for tower crane movement control to review the economic and technical feasibility. Also, Kang et al. [4] virtually modeled site tower cranes to apply algorithms for path planning, path avoiding and optimization and suggested a collision prevention algorithm in order to operate multiple tower cranes. As the most recent study in relation to this study was a study that suggested a robotic crane lift path tracking system using the laser distance measurement sensor as suggested by this research team [5]. The lift path tracking system using laser devices has the advantage that the movement distances of the material can be measured at real times and the effectiveness was proved through experiments. This system tracks the location of the material being lifted by measuring the horizontal rotation angle of the boom shaft, the horizontal movement distance of the trolley and the vertical movement distance of the hook. The vertical movement distance of the hook is made to be measured by attaching a reflection plate to the hook and attaching a laser sensor to the trolley. In the case of this system, there was a concern that if the length of the cable becomes longer, the hook might shake laterally. It was reviewed through experiments and the result indicated that when the hook had moved up to around 30m, the hook would not shake so much as to go out of the range of measurement and even if it would go out of the range of measurement, it would soon detect the laser again. Therefore, the review indicated that the proposed system could be used for general high-rise building construction works. However, in special situations such as in skyscrapers with the cable length of 100m or longer, problems may occur if the hook goes out of the central axis for a long time due to inertia while it is moving horizontally thus this study reviewed the applicability of the alternative technology using encoder sensors and the problems.

2.1 Existing lifting processes

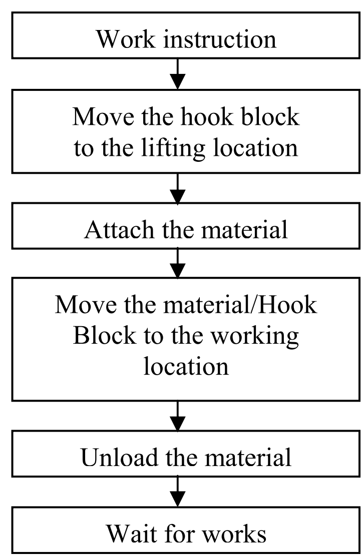

Figure 1. Lifting process

In construction sites, tower cranes are used in most of the works. In the case of apartments, tower cranes are used for those works such as transportation of materials, transportation/installation of assembly type PC etc and tower crane lifting plans are more important to meet schedule working time in steel frame works. Furthermore, in steel frame structure building works, the productivity and efficiency of works for lifting and assembling of steel frame materials were determined by the harmony between the tower crane operator and the signaler. The Flow Chart shown below is a summary of the lifting procedures used in construction sites made by Lee, Jeong Ho et al. [1] which analytically shows the stages of lifting works.

3. INTRODUCTION TO THE LIFT TRACKING SYSTEM

The intelligence type lift control systems apply sensor element technologies to Luffing Tower Crane frames. To track the location of the material being lifted, this system collects x, y and z coordinates at real times and creates movement paths for the material and accurately tracks the movement coordinates of the tower crane. The robotic crane measures the vertical distance between the top of the main boom shaft of the luffing crane to the hook block, the up/down rotation angles of the main boom shaft and the lateral rotation angles of the main boom shaft to track the material being lifted. For the lift control system in this study, a scenario to use diverse sensors is being reviewed in order to obtain accurate measured values of the location of the material being lifted and the study is progressing with 3 alternative plans to use either laser sensors, encoder sensors or GPS sensors. To obtain accurate measured values of the location of the material being lifted for the lift control system; this study is being implemented with Encoder Sensors.

3.1 Encoder Sensor

To measure tower crane lift distances and grasp the location of the tower crane, encoder sensors that are distance measuring sensors were used. The encoder sensors are optical devices that transform the amount of mechanical changes in rotating shafts into electric signals to output them. They are divided into those using an incremental method and those using an absolute method by the principle of operation. The incremental method installs a slit between the light emitting diode inside and the light receiving element and thereby the light produced by the light projecting element is converted into electric currents. These electric signals are outputted as global pulses. The absolute method divides the central rotation axis into angles ranging from 0° to 360° with a certain ratio and designate perceivable electric digital codes (Binary code, Gray code, Ascii code) to each of the divided angles to output each of the digital codes centering on the rotation axis. Since the digital codes designated by absolute angles are outputted, the absolute values are not changed by whatever electric factors. Currently, the incremental encoders are being used to

vibrations and impacts, additional protective equipment is required.

4. EXPERIMENT TO TOWERCRANE USING ENCODER SENSORS

4.2 Configuration of the equipment

The encoders to be used in distance measuring equipment may be changed depending on the level of detect the angles of the arms of industrial robots, automatic control locations of transporting equipment and conveying equipment, Numeric Controls

4.1 Overview of path tracking module s

To automate tower cranes, the operator must know the location of the tower crane and the location of lifting through the server computer. To track the location of materials and the location of the tower crane, distances may be estimated using sensor technologies.

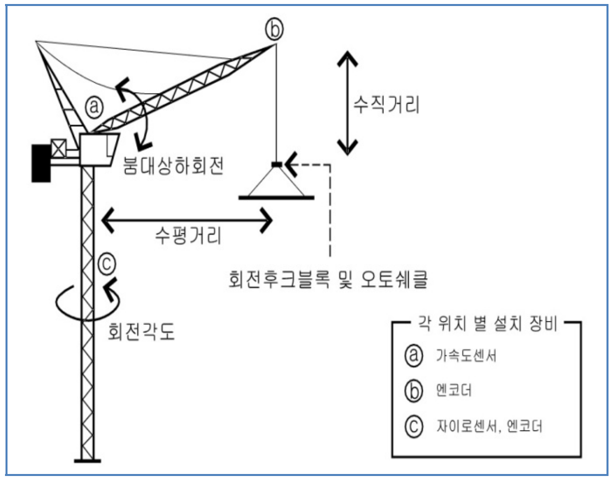

Figure 2. Encoder Sensor Tower crane overview

Figure 1. shows a scenario where encoder sensors are applied to existing luffing tower cranes. Using computer technologies, vertical distance information, horizontal distance information, rotating angle information should be collected to be prepared for lifting of materials. A conceptual description of this system is that encoder sensors are attached to tower crane ropes to measure the vertical distance of the hook block and acceleration sensors are attached to the joints between the boom shaft and the turn table to measure the up/down rotation angles of the boom shaft. The up/down rotation angles the boom shaft are measured to measure the horizontal distance of the tower crane and the horizontal distance between the material and the tower crane changes depending on the angles of the boom shaft. Also, the rotation angles of the tower crane are measured by installing encoder sensors and thereby collecting Z values. The scenario using encoders as described in <Figure 1> can be easily installed into existing tower cranes and can measure accurate data. However, since encoder sensors are weak to

obtaining measured values. Encoder sensors are suitable to measuring angles, locations, number of rotations, speeds, accelerations and distances that are used in various machine tools and general industrial machines for multiple purposes. Of the incremental method and absolute method encoders described earlier, an incremental rotary encoder used to accurately detect the locations of moving parts of industrial NC, robot, sub motor, OA devices etc was used here. However, since encoders are delivered of the movements of pulleys through coupling rather than directly delivered of the power, they have the weakness that errors may occur thus the joints should be accurately fastened.

4.3 Experiment to track the location of a tower crane

Figure 3. Encoder sensors test

The study measured vertical distances and horizontal distances through two incremental rotary encoders to correct errors. To determine if these encoder sensors could detect accurate locations, they were installed into an actual T type tower crane to perform measurement experiments. As shown in Figure 2, the experiment equipment consists of two encoder sensors directly installed into the tower crane, an indicator, a UMPC (Ultra Mobile PC) installed on the hook block to measure distances and a laser sensor module. In the experiment, the encoder sensor was installed on the front part of the cable drum that is used to wind up the rope to the hook block of the T-type tower crane to measure the horizontal distance of the crane. Also, the system was designed to allow the crane operator to see the values measured through the sensors through the indicator attached to the cabin so that he/she can see the moved locations of the hook block. In addition, to verify the accuracy of the distances measured by the encoder sensors, a laser sensor module already verify through in-house tests was installed on the ground and a reflection plate was attached to the hook block to measure actual vertical distances. The overall content of the experiment is as below.

4.4 Analysis of the experiment and test of the hypothesis

The sensors were attached to the tower crane and experiments to measure distances ranging from 하여 1m to 30m were performed outdoor. The result of the experiment was analyzed using SPSS 12.0 program using single sample t-test (one sample t-test). Table 1 shows the result of analysis and to review the result for 2m, the degree of freedom is 59 indicating that the error in the distance measurement was larger than 10cm at the significance level of 0.05.. As shown in table 2, it was indicated that errors in the distance measurement were 1 m or more in all the areas. In the measurement section 2m, the encoder sensor and the laser sensor showed the error of around 3cm but when the measurement section was 10m, the errors were 1m or larger indicating the inaccuracy of the distance measurement by encoder sensors.

4.5 Problems appeared in the experiment

The scenario to attach encoder sensors to the tower crane in an attempt to measure distances was linked to the measurement of the vertical lifting distance of the tower crane by applying laser distance measurement modules and this was verified through experiments measuring error rates. However, through the result of the above mentioned experiment, it could be seen that when the measuring distance was 10m or longer, the encoder showed the errors of 1m or larger and the range of errors increased with the distance. After the experiment had finished, the problems were analyzed and the result can be summarized as follows. First, friction power was not sufficiently delivered to the encoder sensor. Although the encoder sensors measured distances accurately when measuring distances indoor, the installation of the encoder sensors on the tower crane prevented sufficient friction power from being delivered to the pulley thus slipping occurred increasing the range of errors. The existing method of installation installed the rope on the pulley in one direction as shown in Figure 2 thus it is considered that gaps occurred between the pulley and the encoder sensor thus sufficient friction power was not delivered. Second, the encoders went out of the initially installed position due to vibration. As mentioned earlier, the encoder sensor was attached to a turn table and was installed in a temporary manner in front of the cable drum. This method of installation made the sensor sensitive to the impact produced by the movement of the tower crane to go out of the initially installed position to create errors.

Division		Content
Purpose		To check errors in the distances measured by the distance measuring device (encoder sensor prototype) installed in a tower crane
Experimental equipment		Laser sensor distance measuring module, storage battery(12V, 4A), UMPC(Ultra Mobile PC), level, tape measure, connection jack(RS-232, USB cable), general reflection plate(woodrock plate, L xW: 900x600), encoder sensor , Indicator, Power supply, Sever Controller
Place		Chonan city, Chungnam
Variable (distance)		2, 5, 10, 15, 20, 25, 30m
Experiment method	Actual tower crane experiment	1. Measurement of the entire vertical distance a. Install a reflection plate on the hook block of the tower crane on the ground and attach a 40m tape measure b. Lift up the hook block of the tower crane as highly as possible. c. Measure the maximum vertical distance with the laser sensor module installed on the ground(measure the length of the entire rope) 2. Experiment of distance measurement by the encoder sensor prototype a. Install the encoder prototype on the front part of the drum of the T/C(to measure vertical distances) b. Record the value measured by the laser device for each measurement variable(distance) c. Measure the distances with the laser module installed on the ground and with the tape measure(The distance between the trolley and the hook block can be measured by deducting the value measured on the ground from the entire vertical length) d. Collect the data with the computer
Test method	Hypothesis	H0: error in distance measurement > 0.1 m
		H1: error in distance measurement <= 0.1 m
	Test	Single sample t-test(one sample t-test)

Table 1. Overview and plan of the experiment

Therefore, it is thought that the encoder sensors must be directly fixed onto the tower crane to reduce the occurrences of errors. Third, the distance unit displayed on the indicator should be cm instead of m. The experiment was performed using the unit of m. Since the displays of the information collected by the sensors were made using the unit which was bigger than the self error range of 0.1cm, it was difficult to finely adjust the tower crane. Grasping this point, it was attempted to change the measurement unit to cm in order to reduce errors but there were difficulties in changing the unit.

fTable 2. Towercrane distance measurement t-test result

Distance (m)	Mode (m)	Mean (m)	Mean error	Standard devision	t	Degree of freedom	Significance probability
2	1.92	1.9707	0.00714	0.05529	-0.005	59	0.996
5	5.94	5.9428	0.00079	0.00613	0.042	59	0.967
10	11.14	11.1405	0.00028	0.00220	0.000	59	1.000
15	16.34	16.3518	0.00063	0.01900	0.014	59	0.989
20	21.51	21.5100	0.00063	0.00487	15.901	59	1.000
25	26.71	26.7142	0.00093	0.00720	4.483	59	0.972
30	31.43	31.4323	0.00127	0.00981	20.026	59	0.979

5. CONCLUSIONS

To build up tower crane lifting systems, studies are being implemented using distance measuring sensor modules, encoder sensors and GPS sensors respectively. In this study, encoder sensors were selected as a method to track the location of materials thereby measuring the location information of the hook bloc. As a way to implement the study, a prototype was produced to perform experiments to measure encoder distances in order to verify the accuracy of the sensor. However, based on the result of the experiments, the resultant values exceeded the permitted error of 10cm thus plans to solve this problem are being groped. Later, the author is planning to measure the coefficient of extension of the rope with different weight of the material attached to the hook block and perform experiments to generally compare the values measured by the 3 kinds of sensors mentioned above in order to select a sensor suitable to the automatic tower crane lifting system.

6. ACKNOWLEDGMENT

This work was supported by the Korean Institute of Construction & Transportation Technology Evaluation and Planning (KICTEP) with the program number of "06-Unified and Advanced Construction Technology Program-D01." We are grateful to Jong-Sun Kim at M Technology for his help in the fabrication and experiment of the encoder device.

REFERENCES

[1] Lee, J et al., “A study on the work efficiency important of the tower crane operation using GPS and Machine Vision”, 대한건축학회논문집(구조계), Vol. 11(11), pp133, 2002.

[2] Yun, S et al., A Study on a Method for Tracking Lifing Paths of a Tower Crane using GPS in the BIM Evironment”, 대한건축학회논문집(구조계), v.24 n.6, pp163, 2008

[3] Rosenfeld, Yehiel, Automation of existing crane: from concept to prototype, Automation in Construction, Vol.4, Issue 4, pp.285, 1998
[4] Kang et al., Planning and visualization for automated robotic crane erection process in construction, Automation in Construction Vo;. 15, Issue 4, pp.398, 2006
[5] Lee, G, "A Laser-technology-based Lifting Path Tracking System for a Robotic Tower Crane", Automation in Construction,