Development of Object Detection Technology Using Laser Sensor for Intelligent Excavation Work

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Abstract

The demand for the development of intelligent construction equipments is increasing gradually to deal with the current problems of construction technology such as lack of skilled workers, aging of engineers, safety issues, etc. Especially, earth work such as excavation is very machine-dependent, and there have been many researches on the development of intelligent excavator. This requires a great safety concern. Thus, the objective of this study is to develop the technology of enhancing the safety of intelligent excavation system by developing the essential technology of object detection for the intelligent excavator and applying it to a user-friendly system. Literature was reviewed, and the function of various sensor technologies was investigated and analyzed. Then, the best laser sensor was selected for an experiment to determine its effectiveness. Object detection algorithm was developed for a user interface program, and this can be used as the fundamental technology for the development of a safety management system for intelligent excavation work.

Keywords: Sensing, Laser Sensor, Backhoe Excavator, Automation, Safety Management

1. Introduction

Recent Korean construction industry is following the trend of state-of-the-art facility, complexity and gentrification in response to various demands of the consumers, and the attainment of the essential technology has been the key to keeping the competitive edge. Additionally, the generation of high added-value has been the objective of the construction industry to maintain the competitiveness in response to free market influence of construction industry. Nevertheless, construction industry has been traditionally regarded as one of 3D (dirty, difficult, dangerous) work, and the retention of young experienced workers has been a big problem due to the avoidance of young workers delving into the construction work. Old workers, who have been the main workhorse for the modernization in the past, have become aged, while the ratio of young workers desiring to be the main workhorse for future construction market has decreased considerably. Accordingly, the imbalance of supply and demand for construction workers has become a serious issue, and, moreover, industrial accidents have been reported the most in the construction industry. Figure 1 illustrates this point.

These problems of lack and aging of skilled workers and safety problems lead to the reduction of worker's productivity, worsening of the payback on investment due to increased wage, difficulty in maintaining the quality and safety as well as decreased competitiveness in construction technology. These are the current and impending issues for domestic construction industry. Accordingly, the development of automated construction equipments can be regarded as the best technological approach to solve these impending problems.

This study aims at developing an object detection technology for obstacles around the excavator using laser sensor in order to enhance the safety of the earth work environment. Literature was reviewed, and the function of various sensor technologies were investigated and analyzed to identify and select the best sensor.

Object detection algorithm was developed, and this was applied to safety management system for efficient operation and management of construction equipments.

Since the development of automated construction machine is in the initial stage, this study limited its scope to automated control of intelligent excavator and excluded working environment at inclined surface so as to consider flat (even) surface working environment only. Thus, the scope of this research for the development of an object detection technology for the safety management system of an automated excavator is so limited accordingly.

This study aimed at verifying the object detection performance of a laser sensor, selected as an essential technology. As the preliminary step prior to fully-installed experiment, only functional test and field test were carried out.

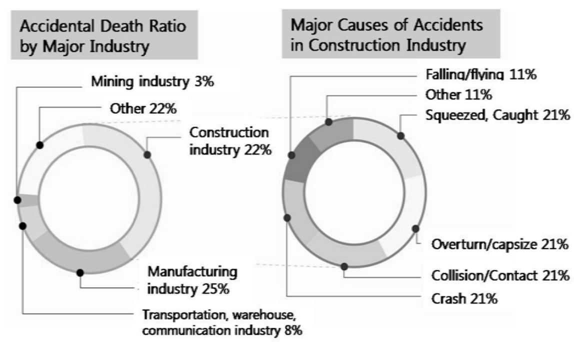


Figure 1 Status of Accidents in Construction Industry (The Korea Occupational Safety & Health Agency, 2006)

2. Core Technology for Object Detection

2.1 Selection of Core Technology

Various conditions applicable to an automated excavator were identified and analyzed for their application to each essential technology.

As a condition required for object detection technology applicable to safety management system, real-time detection must be possible, first of all, and the distance measurement between the object and excavator should be feasible so that the distance to the object can be measured and the collision to the object can be avoided. Additionally, it should be operable during movement or vibration owing to the environmental characteristics, which requires the object detection device to remain attached to the automated excavator.

As seen in table 1, which compared various technologies, sonar sensor and laser sensor were found to be most suitable for object detection.

Sonar sensor of the two previously selected sensors is sensitive to wind effect, and it is also subject to high risk of operation failure during bad weather. Thus, it is difficult to apply it to detection of objects in long distance at earth work field. In contrast, laser sensor is relatively more expansive but is faster in data processing. Moreover, it can detect objects in long distance and at earth work field. Thus, laser sensor was finally chosen for the detection of objects around the excavation work site after comparing all various conditions for the object detection.Mobile robots do not move in a particular direction only, but they use a rotating scan sensor to cover wider area for their mobilization just like the rotating radar at an air traffic control tower. These equipments are widely used, and the laser sensor of SICK is used the most in outdoor environment.

The laser sensor is relatively more expensive, but some of its products are manufactured specifically for outdoor use. Its outdoor performance to scan and sense an object was proven through a field test. Figure 2 shows the result of field test.

Objects at long distance were easily detected, and sensing of objects during rain was also no problem. Left photo (Figure 2) is the actual image, and the image at right is a monitor screen shot, showing the movement of an object by the movement of a line centered on the location of a laser sensor installation toward the moving object.

The laser sensor produced by SICK of Germany was selected finally based on the comparison analysis of economy, stability, application cases, etc. Table 2 shows major specifications of the selected sensor.

Table 1 Comparison of the applicability of essential technologies to object detection

	Real-time Detection	omni-directional detection (360°)	distance measurement (more than 10m)	operability during movement or vibration
Laser Scan (Triangular)	unfeasible	unfeasible	feasible	unfeasible
Laser Scan (TOF)	unfeasible	feasible	feasible	unfeasible
Stereo Vision (Pattern matching)	feasible	unfeasible	feasible	feasible
Stereo Vision (Shape from Shading) (Structured Light)	feasible	unfeasible	feasible requires light	feasible
Intelligent Camera	feasible	feasible	unfeasible	feasible
CCD Camera	feasible	unfeasible	unfeasible	feasible
Sonar Sensor	feasible	unfeasible	feasible	feasible
Laser Sensor	feasible	unfeasible	feasible	feasible

Figure 2 Object Detection by SICK Laser Sensor

2.2 Sensor Operation Algorithm

Figure 4 depicts the sensor activation algorithm for the detection of obstacle objects by the excavating robot, and it is largely divided into a sensor and sensor control system. The sensor is LMS-221 model of SICK and is operated by 24V battery.

When the excavator is being prepared, the sensor is activated at the same time to synchronize the activities. When the excavator begins to work, the sensor is activated so that it can detect any objects within the working environment of the excavator. When the sensor detects an object, it sends a warning signal and stops the excavating work at the same time so as to check for the object. Additionally, when an object is detected, an output of the information on the location of the object can be produced.

Table 2 illustrates the composition of the object detection system using laser sensor. The system can be largely classified into sensor part and control system part. The sensor part consists of the sensor and other devices to make the sensor operable. The control system consists of a computer to have the operation devices connected and operable and a software user interface program to verify object detection. Connection cables and other miscellaneous devices are not illustrated in this table.

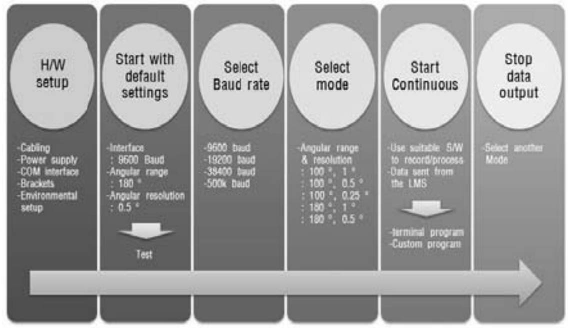
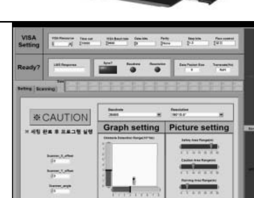


Figure 4 Sensor Activation Algorithms

Table 2 Composition of Object Detection System

Sensor	Laser Sensor	
	Power Supply	
	Brackets	
	24V Battery	
	Serial Hub	
Control System	Hardware	
	Software	

2.3 Sensor Detection Algorithm

Electricity is supplied to activate the sensor at the same time when the excavator is about to work. The sensor is subjected to an activation test with the values automatically assigned, i.e. the angle and speed of measurement and the allocated value of the angle. Then, the sensor begins to detect obstacles, and the software begins to execute its program. The initially allocated values can be changed.

3. Field Test

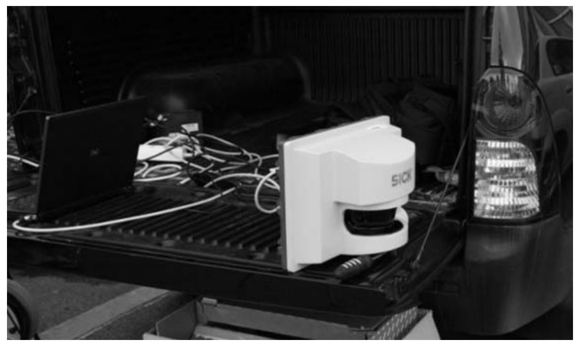


Figure 6 Image of sensor installation for the experiment

Figure 6 depicts the image of the sensor installed at the rear of an ordinary car for a field test. Its rear position was designed so that it can measure the outdoor environment characteristics and the performance during movement in the future experiment after its installation to the excavator.

3.1 Functional Test

Three functional tests were performed. The result of the tests indicated that obstacles at a long distance and moving objects could be detected, and this result could be extended to the earth work field site or even bad weather such as raining.

RS-232 was used as the data interface during field experiment, and the baud rate was set to 9600 for quick data acquisition. 180°/0.5° mode was used for wider measurement range and high resolution. This mode indicates the radius of 180° is sensed, and the detection continues at 0.5° interval.

The lower center of the graph is the location of sensor, and the sensor is set to cover 180° radius and up to 32m distance. When an object is not detected, the green line is marked as a semi-circle. However, when an object is detected, its shape changes by the location. As it can be seen in figures 7, 8, and 9, the place, where an automobile or a pedestrian passes by, the semi-circle shapes changes to a line, which moves toward the sensor depending on the distance.

Figure 7 depicts the result of first functional test. The first test involved the detection performance of the sensor, the distance to the object, and the kind of objects to be detected from the surrounding environment. The test result revealed that all surrounding objects including people, building, tree, stone, etc. could be detected. The place where an object such as an automobile is detected is marked by the circle to show the distance.

Figure 8 depicts the result of second functional test. The second test investigated the performance during raining and compared the output data of the distance and direction of the object in the sensing area with the actual measurement. The result indicated that the sensors operated well under bad weather conditions such as rain and wind. Additionally, the maximum distance error of 0.2m was observed from the measurement distance of 30m, while the direction of the object was accurately sensed.

Figure 9 illustrates the result of the third functional test. The third test involved the performance of the sensor in a very harsh environment of very bad weather and dusty earth work field site. The test result revealed that the sensors performed well at dusty earth work field site on a windy day to detect a person and construction materials scattered around the earth work field site.

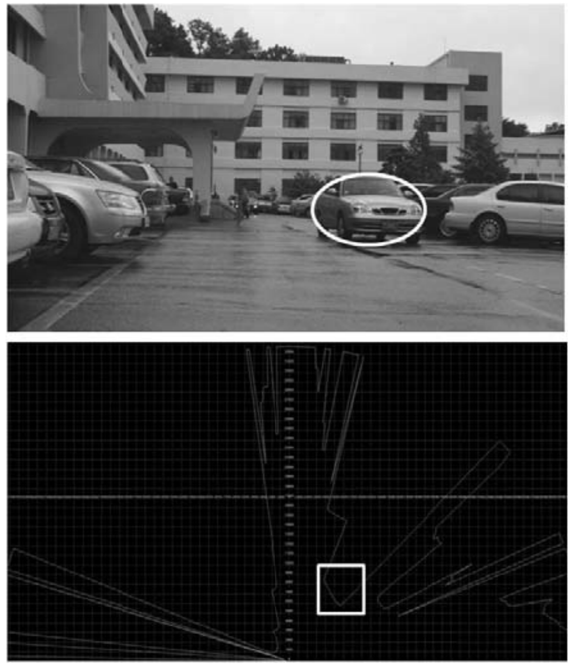


Figure 7 First Functional Test

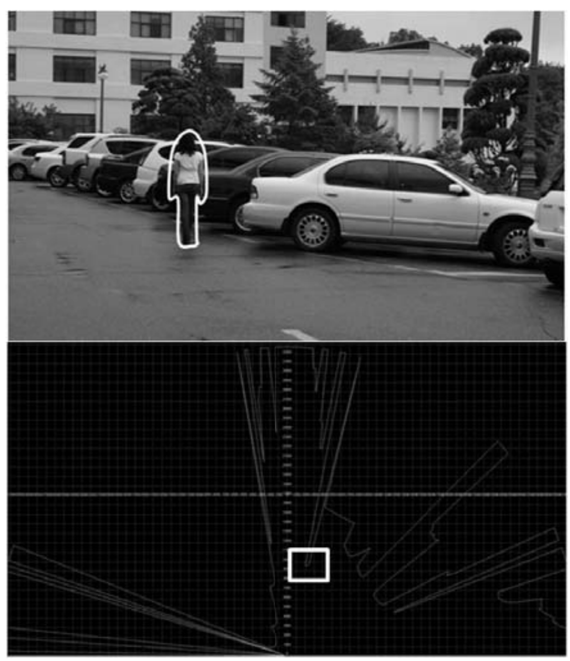


Figure 8 Second Functional Test

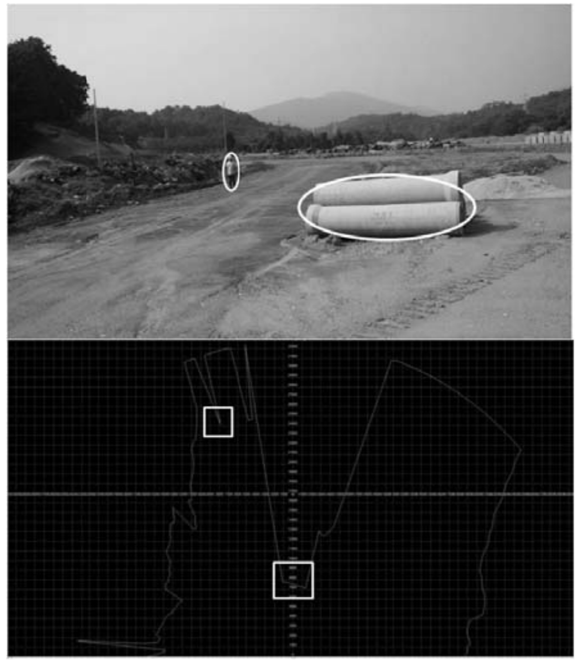


Figure 9 Third Functional Test

3.2 User Interface Performance Test

Three functional tests assessed the performance of the sensors, and two tests of user interface system were carried out. The results of the experiments indicate that the real-time detection of moving objects and obstacles were possible, and the information on the obstacles could be obtained from the user interface system. Additionally, the absolute coordinates, which were pre-set before the start of the sensor, made the detailed information on the direction and location of the objects possible. Additionally, a warning signal could be issued when an object is detected within a prescribed distance.

The bottom center of the semi-circle graph is the location of the sensor, and the sensors were designed to detect the objects at 180° range and up to 32m of distance. The area of detection of the objects is marked by one dot per 0.5° to indicate the location of the obstacle, and the dot is to move with the change in location of the object. Moreover, the dot changes its color depending on pre-specified distance, and a warning sound and message is issued when an object gets within a prescribed target distance. Figures 10 and 11 depict the place, where an automobile or pedestrian passes by, with gathered dots in the semi-circle to indicate the location, and change the color depending on the distance. Additionally, the accurate identification of the location can be possible through the screen conversion of the third grid background.

Figure 10 is the result of the first user interface operation. The test was carried out on still (not-moving) objects, and it was found that the location and distance of the objects were detected fairly well by the sensors. Additionally, the marks for obstacles changed the color at pre-specified distance interval, and a warning signal was issued right after the object appeared within a prescribed distance.

Figure 11 depicts the result of the second user interface operation. The second test was carried out on still objects and a moving obstacle, and the information on the location and distance of the obstacles detected by the sensors was fairly well represented by the user interface.

4. Conclusions

This study carried out a research on the development of object detection technology, which can be applied to earth work field site, as a preliminary investigation of the development of safety management system to be applied to automated excavation system. The following conclusions are derived from this research.

1) The validity of the core technology for object detection, i.e. laser sensor, selected from previous researches was affirmed through a field test.

2) A sensor operation algorithm was developed to apply the selected technology to the object detection system, and an object detection algorithm for the program to provide a user interface was also developed based on this sensor operation algorithm.

3) The developed algorithm was used to develop a user interface, using laser sensors, and the simultaneous operation of this user interface with the sensor was investigated through a field test.

This study carried out the development of essential technology and performance verification experiment only. It is expected and required to conduct additional experiments in the future so that the object detection system is to be installed on an excavator for the verification of the system applicability based on this real-time experiment.

The object detection technology and user interface, which were selected in this study, is expected to be used as the technology for an effective application of safety management system and for the attainment of real-time object detection data and database. Additional field experiments should be carried out to identify the location of the excavator deployment for an efficient application of these technologies. Moreover, if the blind spots can be eliminated with the all directions detection technology, then the developed object detection system can be commercialized.

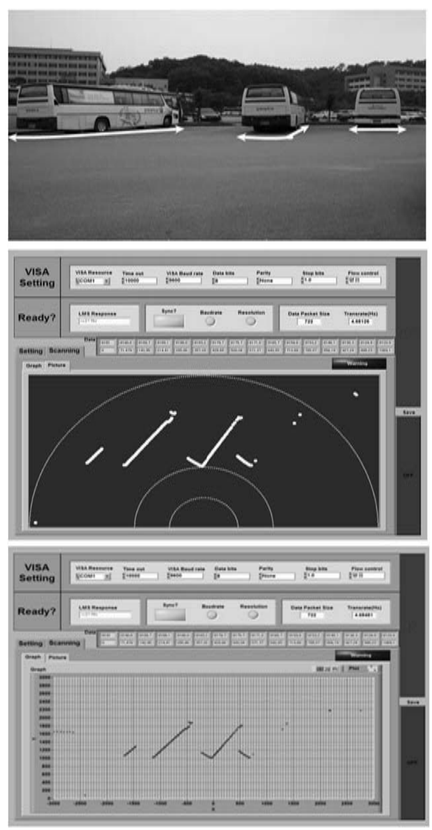


Figure 10 First User Interface Performance Test

5. Acknowledgement

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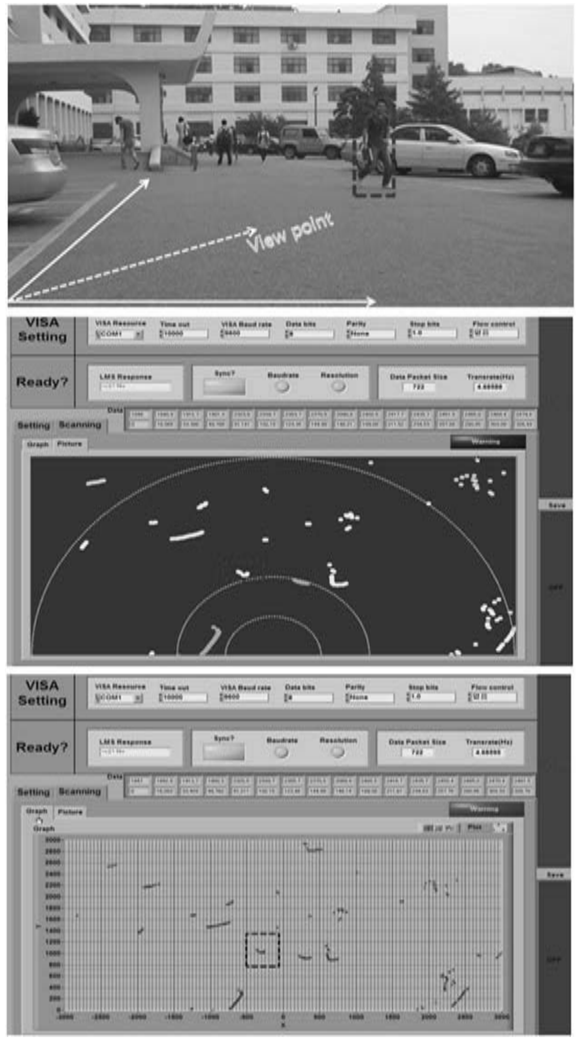

Figure 11 Second User Interface Performance Test

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