Utilization of Laser Range Measurements for Guiding Unmanned Agricultural Machinery

I. G. Jung, W. P. Park, S. C. Kim, J. H. Sung, S. O. Chung

Abstract: Detection of operation lines in farm works, object recognition and obstacle avoidance are essential pre-requisite technologies for unmanned agricultural machinery. A CCD camera, which has been largely used for these functions, is expensive and has difficulty in real-time signal processing. In this study, a laser range sensor was selected as the guiding vision for unmanned agricultural machinery such as a tractor. To achieve this capability, algorithms for distance measurement, signal filtering, object recognition, and obstacle avoidance were developed. Computer simulations were carried out to evaluate performance of the algorithms. Experiments were also conducted with various materials and shapes. Laser beam lost its intensity for poor reflective materials, resulting in less range value than actual, so a compensation technique was considered to be necessary.

Object detection system was fabricated on an agricultural tractor and the performance was evaluated. As test result for obstacle detection and avoidance in field, to detect and avoid obstacle for path finding with guiding system for unmanned agricultural machinery was enable.

Keywords: Laser range sensor, Obstacle avoidance, Unmanned agricultural machinery

Introduction

The increasing need for unmanned agricultural field operations paved the way for the conduct of many researches on these areas in Korea and Japan (Cho et al., 1999; Torri et al., 1999; Umeda et al., 1999). The reported topics include unmanned speed sprayer (Jang et al., 1995), automatic guidance system for tractor based on position-measurement system (Choi, 1990), and automatic steering of tractor (Noh, 1996; Kim et al., 2000).

Major technical elements for unmanned agricultural machinery are posture sensing, electronic machine control, path planning, and obstacle avoidance. As a positioning system for self-propelled farm vehicles, relative sensors for dead reckoning and inertial navigation were utilized in the past. Recently, however, DGPS with high accuracy and an attached Gyro (absolute sensors) were added to relative sensors (Yilin, 1997). The position accuracy of GPS is excellent with minimal error, but the visibility of GPS satellites needed to calculate position is limited by obstacles.

Abrupt appearance of unexpected obstacles (stationary or moving) on operation path is a challenging problem for researchers. Swath finding and obstacle detection have been carried out using CCD cameras, ultrasonic sensors, infrared sensors, or a laser line scanner (Jarvis, 1983; Fujiwara, 1981). Ultrasonic sensors possess low localization accuracy and reflection problem (Kuk and Viard, 1991), while infrared sensors can detect the existence of obstacles although it cannot measure the distance (Flynn, 1988).

A laser line scanner was adopted as a range finding sensor to detect operation line(swath) and obstacles because of the following characteristics (Verdeyen, 1995) : (1) coherence, (2) monochromacity, (3) directionality, (4) brightness, (5) accurate range management, (6) and usefulness in dark environment. Yuta et al. (1991) reported that about 3 seconds were required to consecutively process 256 lines in real time using laser slits and a camera horizontal to ground surface. Cha and Kwon(1994) reported that laser range finder had excellent accuracy, enough to process an image frame with 256 lines within a second.

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Objectives

The general objective of this study is to utilize a laser range finder to detect and avoid obstacles on the path of unmanned agricultural machinery. The specific objectives are to : (1) investigate the characteristics of laser range finder for obstacle detection, (2) conduct computer simulations to determine the feasibility of avoidance algorithm, and (3) evaluate its performance in a field conditions.

Methodology

1. Sensor and Agricultural Machine

Obstacle detection sensors must be wide range detectors, process input signal in real time, measure the distance accurately, and be robust at sunlight. AccuRange 4000-LIR(Acuity Research Incorporated, USA) was selected as the sensor for obstacle detection and avoidance.

A 26HP tractor (Daedong, Korea) was selected for the test. Specifications of the laser range finder and the tractor are given in tables 1 and 2.

Table 1 Specifications of selected laser range finder (AccuRange 4000-LIR)

Items	Specifications
Emitter	780nm IR Laser diode
Effective range	15.2m(Calibrated)
Scanning rate(Motor)	2,600 line/minute(Max.)
Mirror reflectance	96%
Encoder resolution	2,000 pulse/revolution
Sampling rate (ISA Interface card)	50,000 samples/second
Clear angle of scan	300 deg.
Mounted angle to horizontal plane	4 deg.

Table 2 Tractor size and sensing range of the scanner

Items	Specifications
Size(mm)	2,930 × 1,350 × 1,970 (L × W × H)
Power	26PS
Available measurement range (Vertical plane)(mm)	1,333~2,395
Available measurement range (Horizontal plane)(mm)	12,800(±6,400)

Fig. 1 is view of the laser scanner mounted on a tractor for the field test.

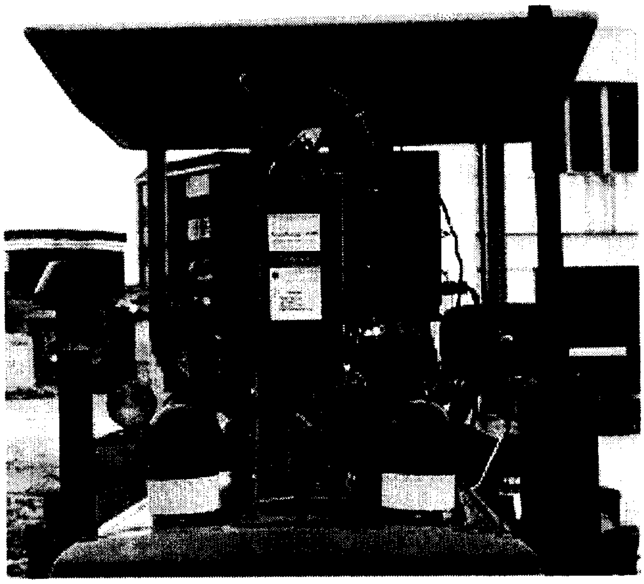
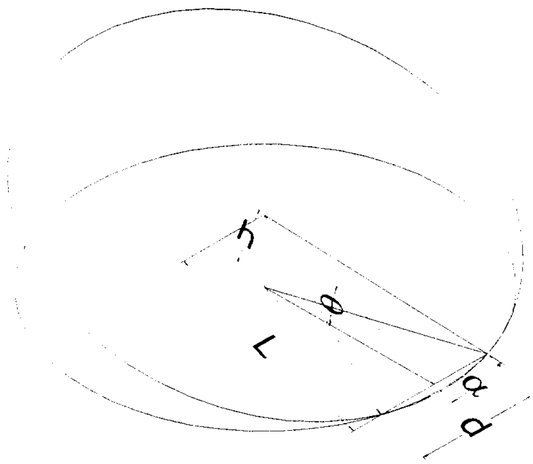


Fig. 1 View of the laser scanner mounted on a tractor.



Symbols	Descriptions
h	Available measurement range (Vertical plane)
L	Effective range
d	Available measurement range (Horizontal plane)

Fig. 2 Available measurement range of scanner mounted on a tractor.

The laser line scanner consists of a NIR (band 780nm) diode pulse generator, a pulse receiver, a rotating mirror, a driving motor, and encoders. It processes received pulses as follows : (1) initialize an interface card and set communication parameters, (2) generate data table for temperature correction, (3) read data from the interface card, and (4) calculate distance between the sensor and obstacles.

2. Signal Processing and Basic Test

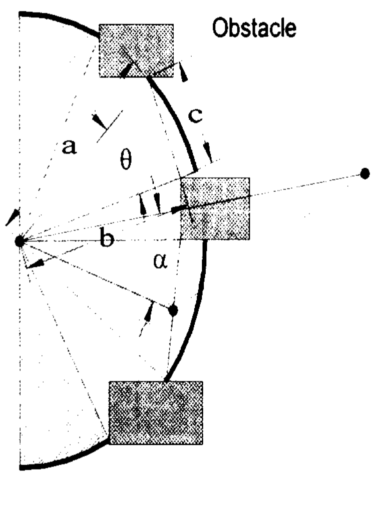
Data received by a laser range finder contain noise that has to be processed and removed. The noise was removed by comparing the other true values, and filtered data were processed by segmentation and thinning algorithm commonly used in image processing.

To confirm performance of the selected laser range finder as an obstacle detection sensor, several basic tests were carried out. Maximum recognition distance was determined and the performance of the sensor was evaluated for various materials at different illumination conditions.

3. Algorithm of Obstacle Detection and Avoidance

Once the distance between sensor and obstacle was obtained, the width and shape were calculated using consecutive distances. Candidate points on path for obstacle avoidance were generated, after calculating the distance between obstacles. The point which made the smallest angle with original target point was determined as a next target point (Fig. 3).

The goal in fig. 3 is the next target point on planned travelling pass.



C : width between the obstacles

Fig. 3 Schematic diagram of path with obstacle avoidance algorithm.

The method of steering angle determination that was used in the study is shown in fig. 4 and equation 1. A steering angle for the obstacle avoidance is the heading difference between the next and the previous moving direction (Fig. 4).

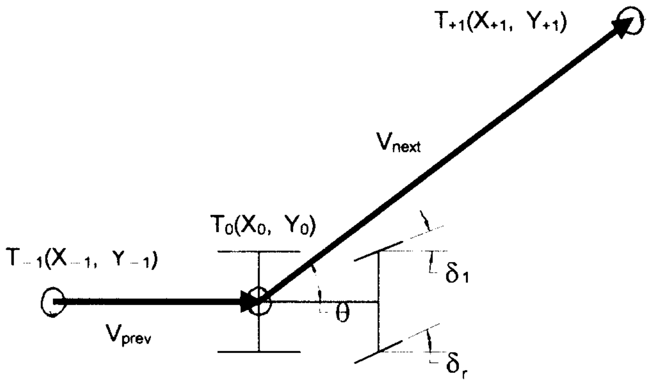


Fig. 4 Schematic diagram of steering angle determination computer simulations and field test.

In fig. 4, T_o is the current location of the tractor and T_{-1} is the previous location of the tractor. T_{+1} is a target point and θ is the steering angle.

$$\vec{V}_{next} = (x_{+1} - x_0, y_{+1} - y_0) \quad \vec{V}_{prep} = (x_0 - x_{-1}, y_0 - y_{-1})$$

$$\theta = \sin^{-1}\left(\frac{|\vec{V}_{nest} \times \vec{V}_{prep}|}{|\vec{V}_{nest}|\,|\vec{V}_{prep}|}\right) \quad \cdots\cdots (1)$$

where,

$$|\vec{V}_{next}| = \sqrt{(x_{+1} - x_0)^2 + (y_{+1} - y_0)^2}$$

$$|\vec{V}_{prep}| = \sqrt{(x_0 - x_{-1})^2 + (y_0 - y_{-1})^2}$$

$$|\vec{V}_{next} \times \vec{V}_{prep}| = |x_{+1}y_0 - x_{+1}y_{-1} + x_0 y_{-1} - x_0 y_{+1} + x_{-1}y_{+1} - x_{-1}y_0|$$

Computer simulations were conducted to evaluate the feasibility of the developed algorithm for the obstacle detection and avoidance, as well as determine an optimum distance between a tractor and a next target point.

The accuracy of a positioning sensor (RTK-GPS : RT-2, NovAtel, Canada) was set at 2, 5, 10, and 20cm. The distance from the tractor to the next target point was set at 1, 1.5, and 2 for the simulations. The receiving frequency of RTK-GPS signal, steering rate, and travel speed of the tractor were assumed to be 2Hz, 0.6rad/sec, and 1m/sec, respectively. The simulation program was developed with Borland C^{++} version 3.1. Field test was also carried out with pre-planned path and artificial obstacles.

Results and Discussion

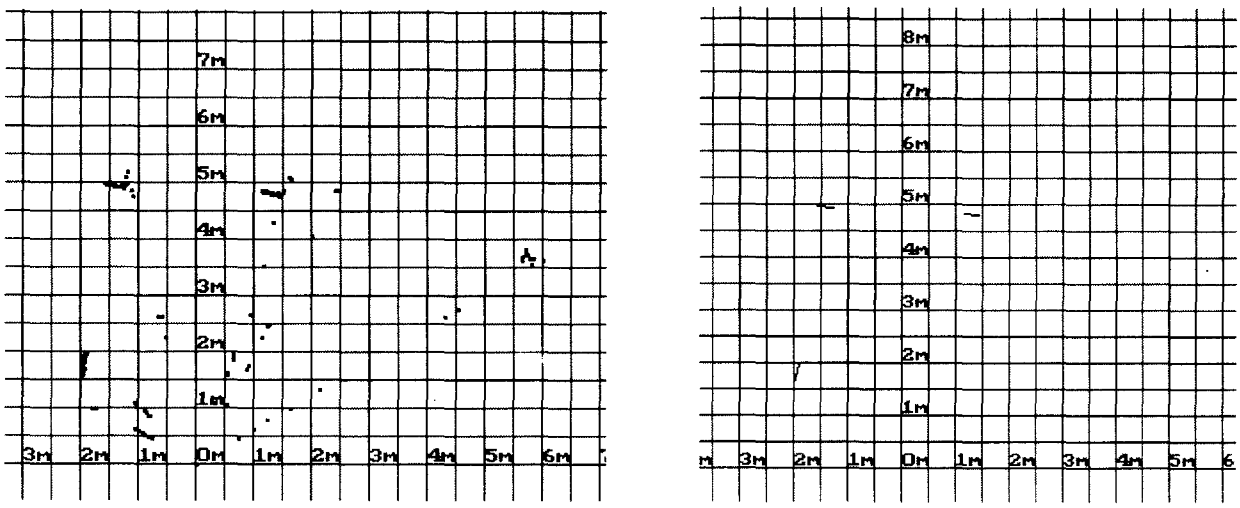
1. Basic Test

The result of noise filtering, signal segmentation, and thinning algorithms is shown in fig. 5. The noise (Fig. 5a) in original signals, was clearly removed such that the shape and position of an object were obtained in 2-D image (Fig. 5b). Fig. 6 is an example of field test for object recognition using a laser range finder and the developed signal processing algorithms, indicating the possible application of the sensor.

The result of obstacle detection at various illumination conditions is shown in fig. 7. Tests were done six times each day and night, with a 4cm-width steel rod. The average distance error in various illmnination conditions was in the range of 0.9~4.7mm. These findings show that a laser range finder was robust at various illumination conditions.

Distance detection tests were also performed using various objects that absorb laser beam such as glass, cloth, and wood. The results indicate that such materials reduce laser strength, but can still detect the existence of objects in front of the tractor (Fig. 8).

The test results of obstacle detection for a car and levee, respectively, are shown in fig. 9 and 10. The width of the car was calculated accurately, and the existence and slope of a levee were also obtained. These test results are detecting results without signal filtering in input signals.



(a) (b)

Fig. 5 Result of signal processing.

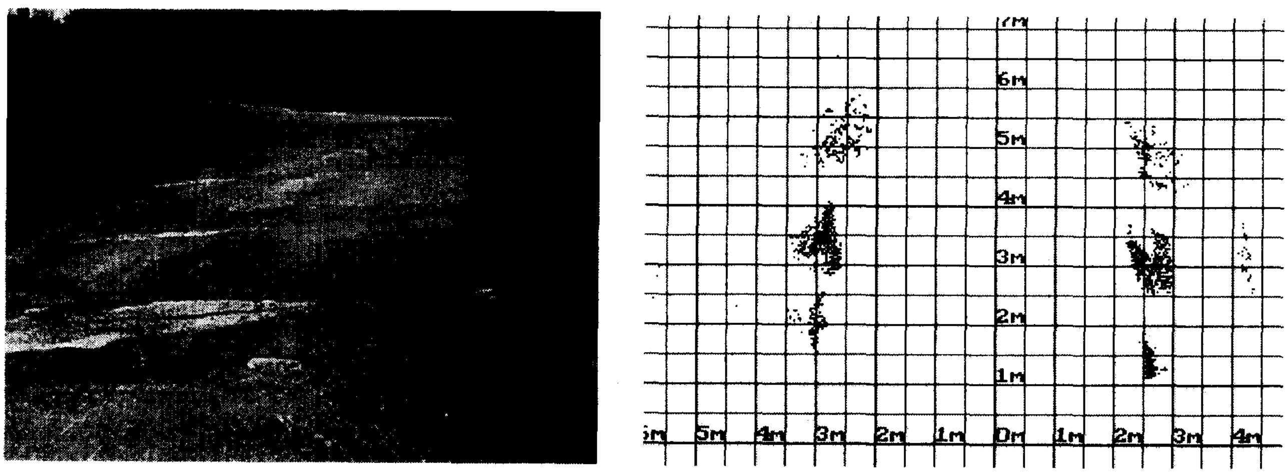


Fig. 6 Result of obstacle detection.

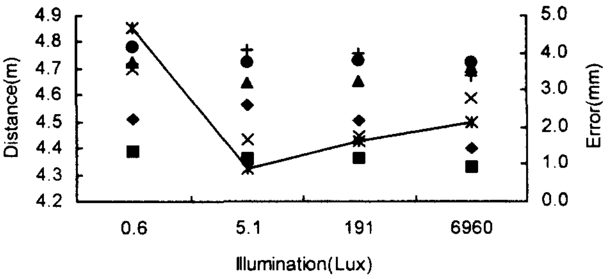


Fig. 7 Detecting errors in each illumination.

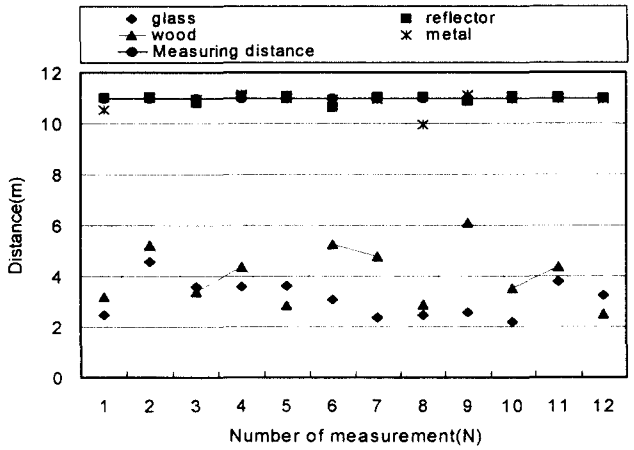


Fig. 8 Detecting errors for different target materials.

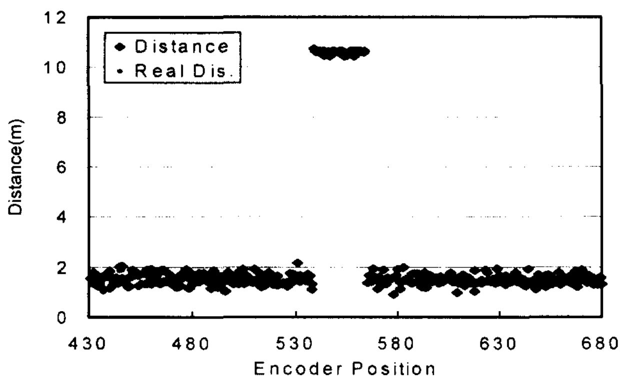


Fig. 9 Detecting result for a stopped automobile.

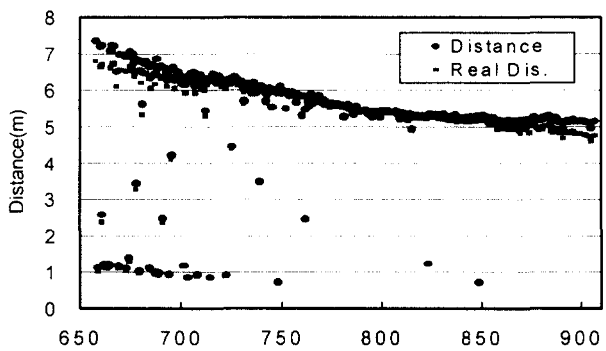


Fig. 10 Detecting result for the slope of the levee.

2. Computer Simulations and Field Test

The results of the computer simulations are summarized in table 3. From the results, the accuracy of the positioning sensor was considered to be critical on the performance of obstacle avoidance algorithm at specific traveling conditions. Based on the conditions given in the study, the maximum error of RTK-GPS was approximately 5cm. An example of the simulation, showing crash of the tractor with obstacles is shown in fig. 11.

Table 3. Path error with respect to DGPS accuracy and the distance from goal of moving tractor to the next goal (unit : m)

DGPS Accuracy(cm)	Distance to target point(m)		
	1	1.5	2
2	2.563	3.312	3.012
5	8.553	5.385	6.039
10	17.523	12.713	13.861
20	39.753	33.258	36.011

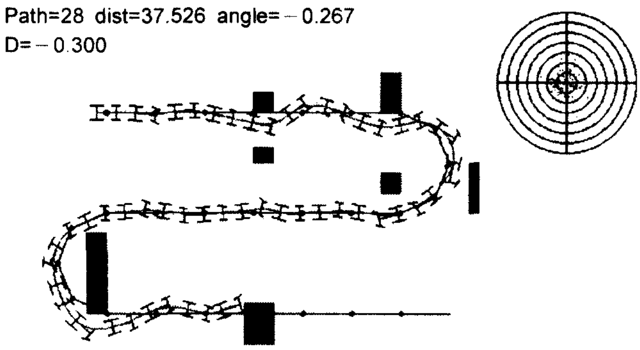


Fig. 11 Simulation result for obstacle avoidance with a 10cm DGPS accuracy.

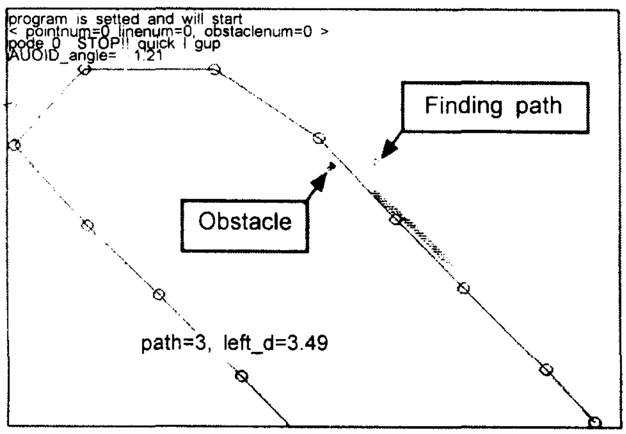


Fig. 12 An example of field test showing the performance of obstacle avoidance system.

An example of field test showing the performance of the system for obstacle detection and avoidance developed in the study is shown in fig. 12. A tractor moved on the planned path without crashing into obstacles placed along the path. In field test, obstacle was man who was near the planned path and test was conducted in three times.

The tractor detected the obstacles and made new target points in each test, thus avoiding the obstacles.

As test result for obstacle detection and avoidance in field, to detect and avoid obstacle for path finding with guiding system for unmanned agricultural machinery was enable.

Conclusions

In this study, a laser range sensor was selected to serve as the guiding eye or vision of unmanned agricultural machinery. Algorithms for distance measurement and filtering, and obstacle recognition and avoidance were developed and computer simulations were carried out to evaluate the performance of the algorithms. Experiments were also conducted with various materials and shapes. Detection system was fabricated on an agricultural tractor and the performance was evaluated. The following are the specific results of and conclusions for the study:

1. The average distance error at various illumination conditions ranges from 0.9~4.7mm, hence, a laser range finder was found to be robust at various illumination conditions.

2. Using objects such as glass, cloth, and wood, the sensor still could detect the existence of these objects in front of the tractor. However, the distance measured by the sensor was actually smaller that the actual distance of the objects.

3. The width of a car was calculated accurately, and the existence and the slope of a levee were also obtained.

4. Based on the computer simulation and field tests, the developed system for obstacle detection and avoidance was found to be feasible as a guiding vision for an automated or unmanned agricultural tractor.

5. Laser beam lost its intensity for poor reflective materials, resulting in less range value than actual, so a compensation technique was considered to be necessary.

6. As test result for obstacle detection and avoidance in field, to detect and avoid obstacle for path finding with developed algorithm was enable.

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