Evaluation of ultrasonic sensors as guidance sensors for greenhouse applications robots

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ABSTRACT

This paper has evaluated the ability of ultrasonic sensors in producing guidance signals for greenhouse applications robots. At first one high quality ultrasonic sensor was selected and some basic experiments were done. Experiments results showed that with predetermined internal parameters, accuracy of selected sensor was good in distances between 15 to 215cm and angles between 0 to 30 degrees. The maximum width of view of each sensor was 17.15cm for flat surfaces and 33.20cm for round surfaces. According to these results, final configuration of sensors around the robot was determined. With designed averaging algorithm it was possible to calculate the averages of orientation and position with high accuracy from ultrasonic sensors outputs. Also, in comparing with reference sensors data, the maximum error and RMS for orientation and position were 11.23 deg, 4.036 deg and 3cm, 0.714cm respectively.

Key Words: Ultrasonic sensor, Orientation, Position, Mobile robot, Greenhouse.

1. INTRODUCTION

It is necessary to implement the recent technologies in greenhouses if one wants to have more products with high quality. Using automated machines and robots that can move without rails will be the future technology in greenhouses. Application of robots in greenhouses has many advantages such as reducing labor requirements; minimizing human hazards and increasing quality and quantity of the products.

Many researchers have reported automatic vehicles applications in agriculture. Cho and Ki (1999) applied fuzzy logic controller (FLC) and machine vision technologies for an autonomous speed sprayer in an orchard. Machine vision was used to determine vehicle orientation and four ultrasonic sensors were used to detect obstacles during the operation. The results of simulation and field test showed that the speed sprayer could be operated autonomously by the FLC. Toda et al. (1999) developed a navigation method for a mobile robot via sonar-based crop row mapping and fuzzy logic control. Crop rows are exploited for automatic navigation of a mobile robot without needing to construct artificial landmarks. Iida and Burks (2002) reported measurement of relative position between tree canopy and vehicle using ultrasonic sensors for navigation of a tractor to work in orchards. Singh et al. (2005) built an autonomous robotic vehicle for greenhouse spraying. A fuzzy logic based PD controller was developed to navigate the vehicle through simulated greenhouse aisles using range information provided by ultrasonic sensors. Shin And Kim (2001) developed an autonomous guidance system for small orchard sprayer with ultrasonic sensors.

Design of automatic guidance systems includes two main steps: guidance signals producing and controller design (Tillett, N.D. 1991). When one vehicle is driven manually, the driver sees the path continuously and compares it with desired path and corrects errors for vehicle’s driving. For replacing an automatic guidance system with driver, this close loop should be repeated. Many methods have been developed for agricultural robots guidance according to the way of getting guidance signals from the field such as dead reckoning, machine visions, GPS-based, laser sensors and etc. Many researchers have reported studies about guidance signals producing by mechanical systems (Parrish and Georing, 1970; Grovum & Zoerb.1970; Widden and Blair, 1972; Hilton and Chestney, 1973; Masayuki,1975; Kaleof and Liberfarb, 1976; Kawasaki et. al,1981), electrical signals (Harries and Ambler, 1981; Kawamura and Namikawa, 1984; Lawson, 1985; Shmulevich, et. al. 1989; Gray, 2000), machine vision (Reid and Scarey, 1988; Zhang et. al. 1999; Morimoto et al. 2002) and GPS-based methods (Bell T. ; 2000; Veal, et. al. 2001; Thuilot, et. al. 2002; Rovira-Mas et al. 2005) for Autonomous Agricultural Vehicles (AAVs). We see that during last decade’s guidance signals producing methods have changed from mechanical systems to GPS-based systems. In each project according to desired objectives, available conditions and facilities, one or more of these methods are used. Combination
of these methods will increase accuracy and performance of the system.

The main objective of this project was to make a mobile robot for greenhouse applications. Ultrasonic sensors for producing guidance signals were used. In this paper we studied possibility of using the outputs of ultrasonic sensors as guidance signals for the robot and finding the best configuration of ultrasonic sensors around the robot. The results of basic experiments for getting position and orientation of the robot from the outputs of ultrasonic sensors will be considered too.

2. MATERIALS AND METHODS

2.1. Ultrasonic Sensors

Eight ultrasonic sensors (USS3, Best Technology Company, Japan) were used in experiments (Figure 3). These sensors are connected together in parallel and to a laptop computer via an interface board (USS3 Configurator, Best Technology Company, Japan). Performance of this sensor changes by changing amounts of internal parameters. The internal parameters should be set at first. In the experiments, the internal parameters of sensors were selected for measuring 15-200 cm distances that are suitable in greenhouse applications.

2.2. Reference Sensors

An axial laser range finder (Leica Disto pro4a) showed in Figure 2 was used for measuring actual distances. The Leica Disto pro4a stores up to 800 measured values and can transfer them via interface to a computer. The Leica DISTO pro4a boasts an increased accuracy of ±1.5 mm. A FOG \(^1\) (JG-35FD, Japan Aviation Electronics Industry, Ltd.) was used as angle reference sensor for orientation evaluation (Figure 3). This sensor obtained the actual angles data during the experiment run. This sensor drift angle accuracy is ±0.5 [deg/hour]. A total station shown in figure 4 (APL-1, TOPCON Ltd.) was used as the positioning sensor to obtain the actual position (x, y axes) of the mobile target with accuracy of ±3 mm for fine mode and ±10 mm for coarse mode. The total station was set to fine mode setting.

2.3. Data Acquisition System

Software for acquiring data from all ultrasonic and reference sensors, noise removal, data fusion and calculation of necessary parameters was developed in Visual Studio2008 software with VC++ programming language. The ultrasonic sensors connected to laptop via USB port. FOG is connected to laptop using RS 232 cable. Data of total station sent to laptop via one Bluetooth Serial RS232 Adapter (Parani-SD100). During the experiments the outputs of all sensors saved in the laptop and after that statistical analysis were done using Microsoft Excel 2003 Software. The average of data receiving frequency for all sensors was 11 Hz.

2.4. Experiments

At first two set of experiments were conducted for measuring the accuracy of sensors and finding the best configuration of sensors around the robot. Then, the last experiment was done for finding the accuracy of ultrasonic sensors in orientation and position determination.

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\(^1\) Fiber Optic Gyroscope
2.4.1. First experiment: Sensors Errors in Measuring Distances

The objective of this experiment was to find the ultrasonic sensors accuracies in measuring distances from walls with different angles. The instruments of this experiment were: A laptop computer, two USS3 ultrasonic sensors, an interface board, an axial laser range finder and a carrier. Ultrasonic sensors were installed in front of a carrier with 22 cm distance and were connected to the laptop via interface board. By moving the carrier in front of the vertical walls with 0-90 degree angles in distances from 15 to 250 cm, the output of both sensors were saved in the laptop. At the same time, the exact distances were measured by axial laser range finder. Finally, orientations and positions were extracted from ultrasonic sensors data and compared with actual sensors data.

2.4.2. Second experiment: Actual Detection Area of Ultrasonic Sensors

In this experiment one ultrasonic sensor was installed on a base vertically. One grid paper with 100×200 cm dimensions and 10×10 cm pixels was expanded in front of the sensor. Two objects from plastic with flat and round surfaces were put in front of the sensor and moved in distances from 10 to 200 cm in 10 cm steps. In each point detection of the objects by sensor was considered. Finally the actual detection area for the ultrasonic sensor was drawn by Solid Works 2003 software.

2.4.3. Third experiment: Orientation and Position Determination by Ultrasonic Sensors

In this experiment, an artificial aisle was constructed from wood with vertical walls and 115 cm width and 5m length (Figure 5). Eight ultrasonic sensors were connected to each other in parallel and installed around the carrier (4 sensors on left and 4 sensors on right sides). The sensors were connected to laptop via USB port. By moving the carrier inside the aisle in different paths (30 times) the outputs of each sensor was saved in the laptop. For finding the accuracy of position and orientation, the outputs of reference sensors collected during experiments, too. Figure 6 shows steps of position and orientation determination algorithm. In this algorithm median filter was used for noise removing and averaging method (described in next section) for position and orientation determination.

2.4.4. Orientation and Position Determination Method

According to Figure 7 the amounts of orientation and position were calculated from ultrasonic sensors outputs as follows:

### Calculation of orientation:

- \( \varphi_{il}(t) = \sin^{-1} \left( \frac{d_{il}(t) - d_{ii}(t)}{w} \right) \)  
- \( \varphi_i(t) = \frac{\sum \varphi_{il}(t)}{\text{num}} \)
- \( \varphi_{rk}(t) = \sin^{-1} \left( \frac{d_{rk}(t) - d_{ri}(t)}{w} \right) \)  
- \( \varphi_r(t) = \frac{\sum \varphi_{rk}(t)}{\text{num}} \)  
- \( \varphi(t) = \frac{\varphi_i(t) + \varphi_r(t)}{2} \)

where:  
\( i = 1,2,3 \) and  \( j = 2,3,4 \) and  \( k = 1,2,3,4,5,6 \)

### Calculation of position:

- \( e_{li}(t) = d_{li}(t) - \frac{(w_p - w_u)}{2} \)
- \( e_l(t) = \frac{\sum e_{li}(t)}{\text{num}} \)
- \( e_{ri}(t) = \frac{(w_p - w_u)}{2} - d_{ri}(t) \)
- \( e_r(t) = \frac{\sum e_{ri}(t)}{\text{num}} \)
- \( e(t) = \frac{e_l(t) + e_r(t)}{2} \)

where:  
\( i = 1,2,3,4 \)

- \( e_{li}(t) \): position from sensor i in left side in time t (cm),  
- \( e_l(t) \): average of positions of left side sensors in time t (cm),  
- \( e_{ri}(t) \): position from sensor i in right side in time t (cm),  
- \( e_r(t) \): average of positions of right side sensors in time t (cm),  
- \( e(t) \): final position in time t (cm),  
- \( w_p \): width of path(=115cm),  
- \( w_u \): distance between USS3 sensors in left and right sides(=44cm).
3. RESULTS AND DISCUSSIONS

3.1. First Experiment

The results of first experiment are shown in Table 1. According to these results we can conclude that for having high accuracy in the distance between sensors and objects should be more than 15cm. Also, the maximum turning angle of the robot that sensors can detect objects is 30 degree. So, the robot can not turn more than 30 degree. There are minimum error in sensors outputs and the best detection in straight direction (0 degree).

Figure 8 shows the percent of errors in the outputs of USS3 sensor in different distances. It is shown that in low distances, the error is high. The maximum error is in 15cm and equals to 5.49%. By increasing the distance, the amount of error will decrease and reaches to 0% in about 100 cm but in more than 100 cm the error will increase again and in more than 210 cm it increase very much. So for using from this sensor in distances more than 210 cm we should change selected internal parameters. Fortunately, the common width between rows in greenhouses is 40-200 cm, so we can use from these sensors by selected amounts of internal parameters in greenhouses and the best distances for this application is 15-200 cm.

3.2. Second Experiment

Figure 9 shows the detection area of USS3 ultrasonic sensor for flat and round surface objects. The maximum width of detection area for flat surfaces is 17.15 cm and for round a surface is 33.20 cm. Dimensions of the robot are 60×90cm. According to the results of this experiment, if we want to detect all space around the robot, distance between two sensors in each side should be between 17 and 33 cm. So the sensors will install in 30 cm from each other. And by having 3 sensors in left and right sides and 2 sensors in front and rear sides around of the robot will be detected completely. In total 10 sensors are necessary for guidance signal producing and obstacle detection. So, final configuration of the sensors around the robot will be such as figure 10.

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<th>Table 1. The results of first experiment*</th>
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* Distances unit is cm and angles unit is degree. + Sign means that detection occurred in that position.
3.3. Third Experiment

Results of third experiment are shown in Figures 11 to 13. Figure 11 is a sample of ultrasonic sensors output before and after noise removal. The noises of ultrasonic sensors are random, so the best method for removing them is to use median filter. From this figure one can see that this filter can remove noises very well. Although using this filter will have about 0.5 second time delay in final output of the sensors that has bad effect on exact guidance of the robot in desired path in high speeds, but the speed of the robot is low during operation in greenhouses so this delay does not have much effect on the exact guidance of the robot.

Figure 12 shows the position determined from ultrasonic sensors and actual position from total station. We can see that averaging algorithm can calculate the position from corrected outputs of sensors well. Because of time delay in sensors final output, there is 0.5 second time delay in positions too. The maximum error is 3 cm with RMS of 0.714 cm. The results of Singh et al. (2005) showed an average of RMS about 2.5 cm for aisles with 61 cm width. The amount of RMS in here is less than results of Singh et al. (2005) because they used only one sensor at each side of robot but we used 4 sensors in each side. We can conclude that if more sensors are used, we will have more accuracy in determination of robot’s position, but it will increase the cost of robot’s system. So, we should select the number of sensors according to the accuracy that we need and the amount of money that we have.

Figure 13 compares the orientation from ultrasonic sensors and actual orientation from FOG sensor. It is shown that averaging method can calculate the orientation from corrected outputs of ultrasonic sensors. Because of time delay in sensors final output, there is about 0.5 second time delay in orientation too, so we should try to decrease this time delay. The orientation’s maximum error was 11.23 degree and RMS was 4.036 degree. From the results of this experiment, we can see that the accuracy of ultrasonic sensors in determining position is very good and enough for greenhouse applications but the results for orientation are not accurate. So we should use other angle sensors in the project too. And by fusing the results of orientation from ultrasonic sensors and the output of extra angle sensor we can get exact orientation of the robot.
4. CONCLUSIONS
The main objective of this research was to build a mobile robot for greenhouse applications. We can use from this robot for spraying, harvesting, pots and products transportation and etc. by adding special actuators and manipulators on it. From the experiments in this paper the following results were found:
1. It is possible to use ultrasonic sensors for guidance signals producing of the robot.
2. There are minimum error in sensors outputs and the best detections in straight directions (0 degree).
3. The maximum turning angle of the robot with selected internal parameters is 30 degrees.
4. The best configuration of the ultrasonic sensors around the robot was found from the detection area of the sensor.
5. We can simply get position and orientation of the robot from ultrasonic sensors outputs by averaging method.

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