Part IV

Conclusion

Chapter 11

Conclusion

In this thesis, I proposed two new ultrasonic sensing methods for mobile robots, which are fast and accurate bearing measurement method by a single transducer, and fast and accurate direction measurable sonar-ring method. At this final chapter of the thesis, I will discuss the proposed methods based on the purpose of this research, and then conclude this thesis.

11.1 Discussion

At introduction, I have explained importance of external sensors and requirements for those sensors in practical use. Those requirements were [Everett 95]:

- **Real-time operation** – The update frequency must provide rapid, real-time data.
- **Size** – The physical size and weight of the system should be practical with regard to intended mobile robot.
- **Power consumption** – The power requirements should be minimal in keeping with the limited resources on board a mobile robot.
- **Simplicity** – The system should be low-cost and modular to allow for easy maintenance.
- **Field of view** – Should be wide enough with sufficient depth of field to suit the application.
- **Accuracy and resolution** – Both must be in keeping with the needs of the given task.

Grounded on those requirement for mobile robots, purpose of this research was set as the development of highly efficient ultrasonic sensors for indoor mobile robot environment recognition. As explained before, Many objects in indoor environment are specular for ultrasound wave used in the air. Therefore, development of good direction measurable

ultrasonic sensors are the most important for using ultrasonic sensors on mobile robot. Moreover, simplicity and real-time operation are important for implementing on a real mobile robot and using this sensor while moving.

Accordingly, this research has aimed at the development of ultrasonic sensing system for indoor mobile robots which fulfill following points: accurate direction measurable, simple and real-time operational. Based on the aims, I proposed two method which can measure accurate direction to the reflecting point rapidly.

I would like to see two proposed methods how much they are satisfying those requirement.

11.1.1 Bearing measurement by a single transducer

This method achieve fast and accurate bearing measurement by a single ultrasonic transducer using character which frequency of echo signal depend on direction which the echo is coming back from. It can measure more accurate bearing angle than beam width using difference of frequency.

This simple method has two big advantages:

- Simplicity of hardware. It can measure accurate bearing angle by using just a single ultrasonic transducer.
- Fast measurement. It can measure accurate bearing angle by using simple process to detect difference of frequency, and consequently we can achieve fast measurement.

For satisfaction to indoor mobile robots, the process of this method employs detecting zero-crossings and using look-up table. Consequently this is perfect real-time operating system for indoor mobile robots.

The system require only a single transducer, transmit circuit which can generate a pulse, and receiver circuit which can detect zero-crossings are required in hardware. Comparing any other direction measurable ultrasonic sensing method, this method is the simplest in a total system. Bearing accuracy of this method is about ± 1 degree, and this is sufficiently more accurate than beam width of transducer. A wide band electrostatic type transducer requires bias voltage to use, however it is very small and we can say this is low power consumption system. Considering field of view, depth is sufficient as same as conventional ultrasonic sensors, however width are limited, especially because measurable area is limited by limitation of look-up table and symmetry of the look-up table.

In previous researches, simplicity, field of view were sacrificed for measuring accurate direction. Comparing those methods, this method could extremely improve the simplicity.

11.1.2 Direction measurable sonar-ring

This research realized a sonar-ring which can measure multiple reflecting points existing around a robot with good directional accuracy in a single measurement. This method achieved to get wide field of view in a single measurement for environment recognition of mobile robots.

The proposed new sonar-ring sensor has following advantages:

- Wide measurable area of sonar-ring sensor.
- Measurement of all around the robot in a single transmit/receive cycle.
- Accurate directional angle measurement of the adapting multiple receiver. Consequently, it is possible to measure reflecting points on wall, pole, corner and so on.
- Detection of multiple reflecting points in a single measurement.

When satisfaction for indoor mobile robots were considered, field of view is perfectly all around the robot. There are occlusion problem, however, it is impossible to avoid because of character of ultrasound. Directional accuracy is better than one degree and it is sufficient for mobile robots. This is a sonar-ring, hence, it require multiple transducers with individual receiver circuits, but each circuit the same and process are quiet simple, consequently it is possible to construct this system easily and inexpensively. Piezo-electric type transducers do not require bias voltage, hence power only for transmit signal, amplifier and computers are required. In total system, it is low power consumption system. Because of simple process, it is real-time operational for indoor mobile robot.

In previous researches, simplicity, field of view were sacrificed for measuring accurate direction. This method could extremely improve the field of view and directional measurement accuracy.

11.2 Conclusion

Purpose of this research was development of highly efficient ultrasonic sensor for indoor mobile robot environment recognition. As explained at introduction, pulse-echo method ultrasonic sensors are accurate distance measurable, small and light, simple and low-cost and safe for human. However, it can not measure accurate direction, and it is one of biggest disadvantage for indoor mobile robot application. Because many objects in indoor environment are specular for ultrasound wave used in the air. According to this specularity, reflecting place which corresponding to a leading edge of the echo are almost a point. That means, reflecting points in environment are showing quantitative information as like position of a corner or bearing angle of a wall, therefore accurate directional measurement to the reflecting point can give those information which are really useful for environment recognition. For that reason, poor accuracy in direction is the biggest disadvantage for indoor mobile robot.

Considering those advantages and disadvantages, this research aimed at development of ultrasonic sensing system for indoor mobile robots which fulfill following three points – direction measurable, simple and real-time operational.

A point of this research in approach was that the system was made as a closed system including from sensor device which is entrance of information to output which can be apply for various tasks. Moreover, the sensing system is constructed sufficiently to apply for various tasks by making sure of modularity.

Both methods could achieve direction measurement accurately, about one degree. The first method, bearing measurement by a single transducer, is extremely simple using only one transducer and two zero-crossing points. The second method, direction measurable sonar-ring, equipped thirty transducers but each circuit the same and process are quiet simple, consequently it is possible to construct this system easily and inexpensively. Considering operational time, they are real-time operational for indoor mobile robots. Moreover those method are not losing advantages of conventional pulse-echo method ultrasonic sensors.

Recapitulate, two methods satisfy the purpose of this research, and I can say I could develop highly efficient ultrasonic sensors for indoor mobile robots.