Using one bit wave memory for mobile robots' new sonar-ring sensors

Teruko YATA

The Robotics Institute
Carnegie Mellon University
Pittsburgh, PA 15213 USA

Akihisa OHYA, Shin'ichi YUTA

Intelligent Robot Laboratory
University of Tsukba
Tsukuba 305-8573 Japan

Abstract

This research aims at development of sensors for small size indoor mobile robots. We have proposed a new sonar-ring which can measure accurate direction and distance to reflecting points rapidly for this purpose. This new sonar-ring needs to receive echo signal by multiple receivers and to detect multiple Time-of-Flights (TOFs) in received signal at each receiver simultaneously for achieving fast and accurate measurement. However, it is impossible to satisfy them by conventional circuit. This paper proposes 30 channel 1 bit wave memory system to achieve these two points simultaneously and shows its usefulness.

1 Introduction

We have proposed a new sonar-ring which can measure accurate direction and distance to reflecting points rapidly [1]. The new sonar-ring sensor which take advantages as follows:

- Good distance accuracy as same as the conventional ultrasonic sensor
- Accurate bearing angle measurement
- Covering all around the robot in a single measurement, consequently fast measurement
- Multiple objects detectable measurement

This new sonar-ring system have to achieve following two points simultaneously for implementing on a real mobile robot:

- Receive echo signals by multiple receivers simultaneously.
- Detect multiple TOFs in received signal at each receiver.

However, it is impossible to satisfy them by conventional circuit.

Use of wave memory is one of solution for detecting TOFs of multiple echoes. Moreover, it is effective to employ a threshold value to make 1 bit at each channel before memorizing the wave signal. Because it is necessary to mount it on the robot to use it during the robot is moving, but regular wave memory which has large capacity at each channel, and when number of channels increase, size of the total system get very huge.

We propose a memory system which can simultaneously record 30 channels wave data which is binarized by a threshold at receiver circuit in parallel. This system can record 30 receivers data in parallel, and it is possible to implement and use on the robot easily.

In this paper, at first our proposed sonar-ring sensor is briefly explained and then we propose the small size wave memory and its implementation. An experimental result shows the usefulness of this wave memory for the robot to know the environment.

2 Direction measurable sonar-ring

We have propose and constructed a new sonar-ring which can measure accurate direction and distance to reflecting points (Figure 1) [1]. This sonar-ring sensor is based on following four steps:

- Transmit an ultrasonic pulse simultaneously: Rapid measurement is achieved with the omni-directional transmission in a single transmit cycle.
- Receive the echoes with plural wide beam receivers on the circumference: Place the receivers to overlap their directivity, and measure differences of the propagation time of echoes. Each

0-7803-6583-6/00/$10.00 © 2000 IEEE

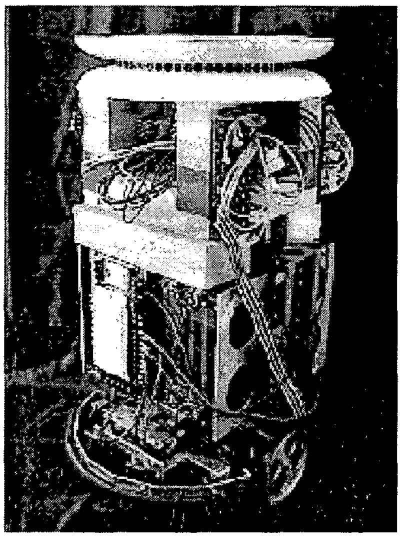

Figure 1: A omni-directional sonar sensor on the Yamabico robot.

Time-of-Flight (TOF) is measured by detecting the leading edge of the echo.

- Detect TOFs for multiple echo blocks at each transmit in each receiver: Since, multiple objects can be included in the beam of each receiver, all echoes should be detected by each receiver to achieve the measurement of these objects.

- Calculate the direction of reflecting points: Accurate bearing angle are calculated from the differences of TOFs.

This sonar-ring sensor is constructed based on following four back ground technology:

Conventional pulse-echo ultrasonic sensors – The pulse-echo ultrasonic sensor is well known for its simplicity and low cost within robotics applications [2]. It can detect easily distance to a reflecting object, however the accurate direction to the reflecting object is not easy to measure with conventional ultrasonic sensors.

Sonar-ring – A sonar-ring sensor is one of the most popular sensor system for indoor mobile robots [3]. Multiple sets of conventional pulse-echo ultrasonic sensors are placed on the ring for measuring all around the robot, and they are driven in sequence to avoid their interference. A conventional sonar-ring is regarded as difficult to measure accurate bearing of reflecting points. Furthermore, it is slow to get full 360 degrees directional information due to sequential driving of the transducers for avoiding interference. Consequently it has been difficult for a mobile robot to move with the sonar-ring in a relatively complicated environment without extra sensor data processes [4].

Accurate reflecting point measurement – The accurate bearing angle measuring methods of a reflecting point using the propagation time difference has already been proposed [5] [6]. In the method, a pulse is transmitted from a single transmitter and an echo which is coming back from the same object is received by multiple receivers simultaneously. However, in case of using a single transmitter and two receivers, the measurable area is only the overlapping area of the directivity of the three transducers, and it is not enough for robotics applications. For that reason, mechanical rotations had to be employed in past research [5] [6], and it requires time to scan and is slow to get information from wide area.

Multiple objects detection – A conventional ultrasonic sensor is detecting only a leading edge of the first echo, consequently it measures only the distance to the nearest object. However, if leading edges of the second and following echoes should be detected for getting more information (Figure 2). For example, when two poles exist in front of a wall and they are distant enough, we can observe three echoes and we can know distance to them just by detecting TOFs of these three echoes simultaneously.

3 Wave memory

This new sonar-ring system have to achieve following two points simultaneously:

- Receive echo signal by multiple receiver simultaneously.

- Detect multiple TOFs in received signal at each receiver.

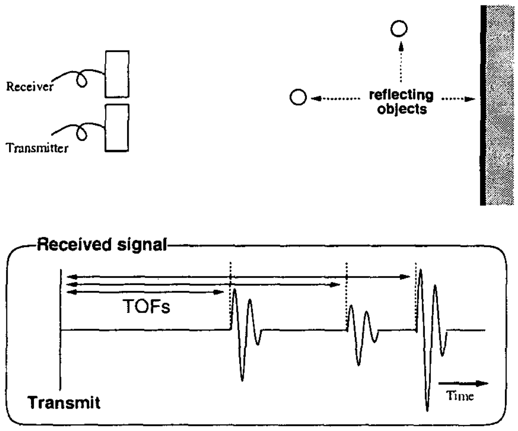

Figure 2: Multiple objects detection by multiple echoes detection.

It is impossible to satisfy by conventional circuit for pulse-echo method which stops a timer by the first coming back echo.

Use of wave memory is one of solution for detecting TOFs of multiple echoes. Multi channeled wave memory is required to detect TOFs of multiple receivers simultaneously. Furthermore, it is necessary to mount on the robot to use it during the robot is moving. However, it is not necessary to have ordinal regular wave memory which has large capacity at each channel, and when number of channel increases, size of which get very huge. Consequently, it became difficult to implement it on the robot.

Use of a threshold value is useful to detect leading edges easily. When the threshold value is used to detect the leading edges, the signal is already binarized and it is just a one bit at each channel. Consequently, one bit for each channel is enough capacity when leading edges of echoes are detected by using a threshold value.

Accordingly, I constructed a memory system which can simultaneously record 30 channels wave data which is binarized by a threshold at receiver circuit in parallel. The system assigned one bit for each receiver and 30 bits from 30 channels data are written on the memory as one word simultaneously. A counter which increments each 1 microsecond (at 1MHz) is attached for generating address signal. This is a binary wave memory with 30 channel for 32k words within 1 microsecond sampling (measurable range is 5m) as shown in Figure 3. This memory can be accessed from CPU anytime but writing received data (Figure 4). The circuit was implemented on the main board of the robot which uses Transputer as CPU. This system can record 30 receivers data in parallel without using an Analog to Digital Converter, and it is possible to implement and use on the robot easily.

The binary wave signal is generated at receiver circuit from output of receiver and a threshold at receiver circuit, and is time sequence signal starting with a transmission signal.

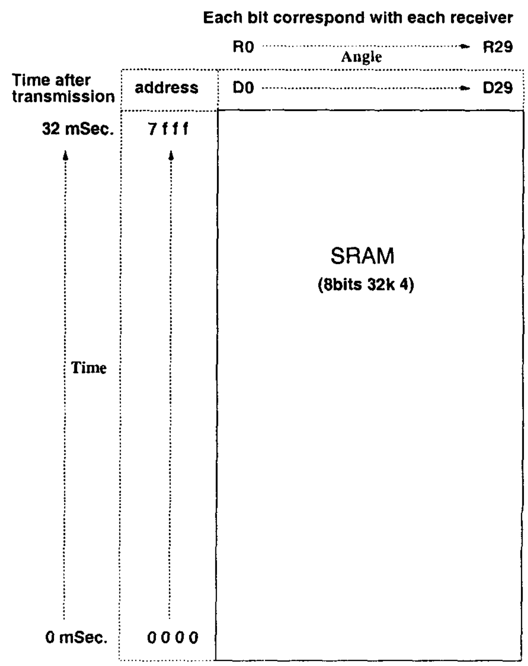

Figure 3: A 30ch 1bit wave memory.

This proposed 30 channel 1bit wave memory system makes it possible to process in software easily, and consequently it could reduce size of the hardware circuit of the sensor system. By this proposed system, it became possible to implement 30 channel sonar-ring which works in parallel on a mobile robot easily.

Process using the memory data

At first, Time-of-Flights (TOFs) are measured by detecting leading edges from data of 30ch 1bit wave memory which has been explained above. TOFs of multiple echoes from multiple objects should be detected at each channel. Those detected multiple TOFs at each receiver are grouped corresponding to each ob-

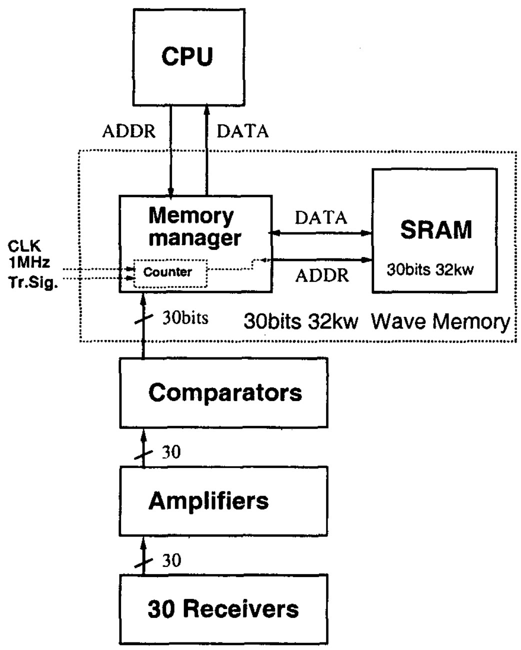

Figure 4: A 30ch 1bit wave memory system.

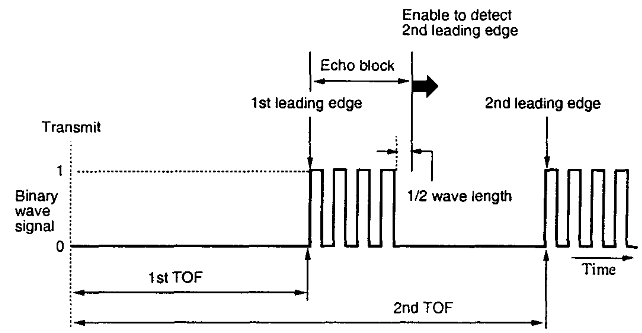

Figure 5: Multiple TOFs measurement from memory data using leading edges.

ject. And then, reflecting points on each object are calculated at each group.

The first leading edge, leading edge of the first echo, can be detected as same way as conventional ultrasonic sensors. The time which the wave signal turn high firstly is the time of the first leading edge (Figure 5).

It is necessary to detect end of the first echo block to detect the next leading edge. In this system, envelope of the received echo is not detected for the purpose of keeping wave information, consequently the end of the echo block can not be detected directly. However, frequency of ultrasound is known and the binary wave signal remains the frequency information. For that reason, it can be regarded the first echo block has ended when the low level continued for more than half wave length period in time since the signal turned from high to low. After detecting the end of the first echo, the next echo can be detected by the same method as the first one.

A deficiency of this method is that overlapping of echoes causes hiding of reflecting points which are near by. The size of the hidden area is depending on the directivity of the each receiver and the duration of the echo pulse. In the experimental system, each reflecting points should be distant more than 17cm. This makes it difficult to apply this system to more complicated environment. This is a kind of occlusion problem in ultrasound sensing.

Multiple receivers are used simultaneously and multiple TOFs are detected by each receivers in this system, and accurate reflecting points are calculated from difference of TOFs reflected from the same object and detected at different receivers.

Consequently, using the implemented system, the robot could achieve following things which was impossible with ordinary sonar-ring:

- Measurement of all around the robot in a single transmit/receive cycle.
- Detection of multiple reflecting points in a single measurement.
- Accurate directional measurement of reflecting points on a wall, a pole or a corner.

4 Experiment

The hardware and software of the fast and accurate direction measurable sonar-ring system was built, and implemented on the robot (Figure 1). Main flow of this system is the same as a conventional ultrasonic sensor: transmit an ultrasonic pulse, receive the echoes and process the received signal.

All processing flow of this system is shown in Figure 6. One cycle of the measurement is as follow:

1. Output a transmission signal from CPU to transmitter circuit.
2. Transmit a ultrasonic pulse by 30 transmitters simultaneously.

3. Receive the echo by 30 receivers in parallel. Following processes are done during receiving the echo.
    (a) Amplify the received signal independently at each receiver.
    (b) Compare the amplified signal with a threshold level at each receiver circuit.
    (c) Write the binarized data into the 30ch 1bit wave memory.
4. Detect leading edges of echo signal from the memory data.
5. Make groups of the leading edges corresponding to objects.
6. Calculate the positions of reflecting points.

In this one cycle, it is possible to detect multiple reflecting points all around the robot in this system.

Result

Experiments using plane and columnar objects were performed using this wave memory system. Plane boards and columnar poles were placed as shown in Figure 8.

Figure 7 shows wave memory data in this experiment. Horizontal line shows bearing each channel corresponding to angle of receivers. Vertical line shows time. Each point shows data which goes over the threshold. Figure 9 shows detected leading edges from the data. Multiple reading edges are successfully detected. Figure 10 shows calculated reflecting points in this experiment ([1] explains the method). The robot is located at the origin of the coordinate axes and six reflecting points were detected. The experimental result shows that the proposed sonar-ring sensor successfully measured the location of the reflecting points in the environment.

5 Conclusion

In this paper, we proposed the small size wave memory and implemented the new sonar-ring system for a mobile robot. The wave memory made possible to process multiple echoes detection on the robot and the experimental result shows the usefulness of this wave memory for the robot to know the environment.

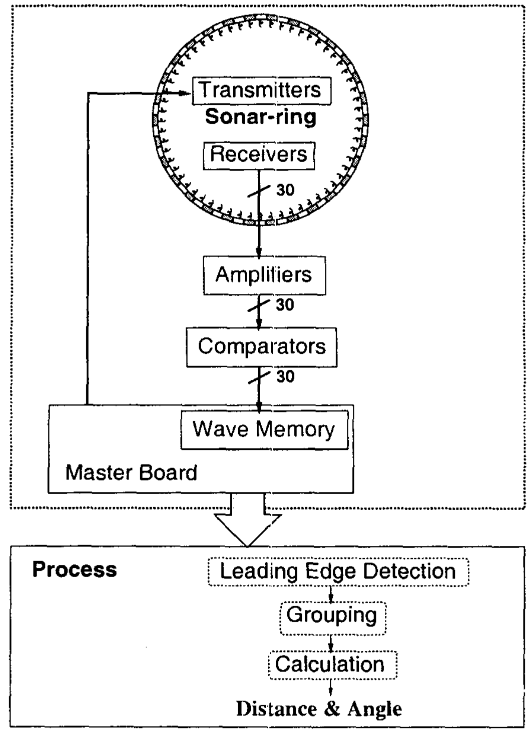

Figure 6: System architecture of the direction measurable sonar-ring.

References

[1] T. Yata, A. Ohya, S. Yuta, 1999. "A Fast and Accurate Sonar-Ring Sensor for a Mobile Robot," *Proc. of IEEE Int. Conf. on RA*, Detroit Michigan, USA. pp.630-636.

[2] H.R. Everett, 1995. Sensors for Mobile Robots: Theory and Application. A K Peters.

[3] S.A. Walter, 1987. "The Sonar Ring: Obstacle Detection for a Mobile Robot," *1987 IEEE Int. Conf. on RA*, pp.1574 - 1579.

[4] J. Budenske, M. Gini, 1994. Why is it so difficult for a robot to pass through a door way using ultrasonic sensors ? *Proc. of IEEE Int. Conf. on RA*, San Diego CA,USA, pp.3124 - 3129.

[5] Y. Nagashima, S. Yuta, 1992. "Ultrasonic Sensing for a Mobile Robot to Recognize an Environment – Measuring the Normal Direction of Walls," *1992 IEEE/RSJ Int. Conf. on IROS*, pp.805 - 812.

[6] H. Peremans, 1993. "A High-Resolution Sensor Based on Tri-aural Perception," *IEEE Transactions on RA*, Vol.9, No.1, pp.36 - 48.

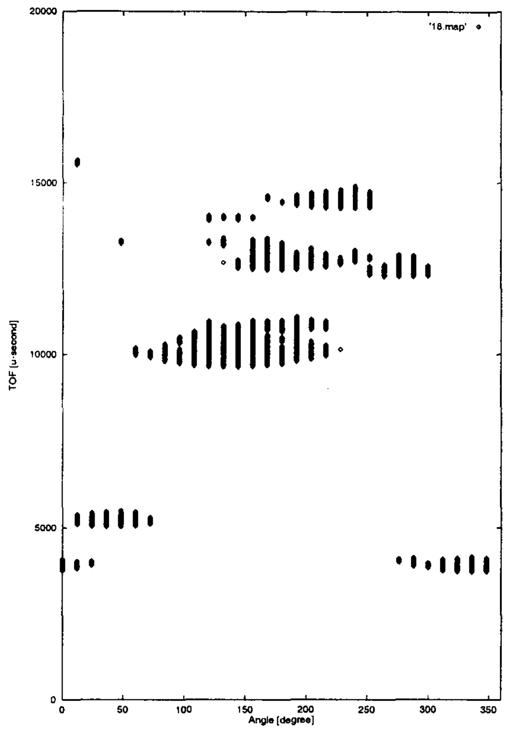

Figure 7: 30 channel 1 bit wave memory data. Horizontal line shows bearing each channel corresponding to angle of receivers. Vertical line shows time.

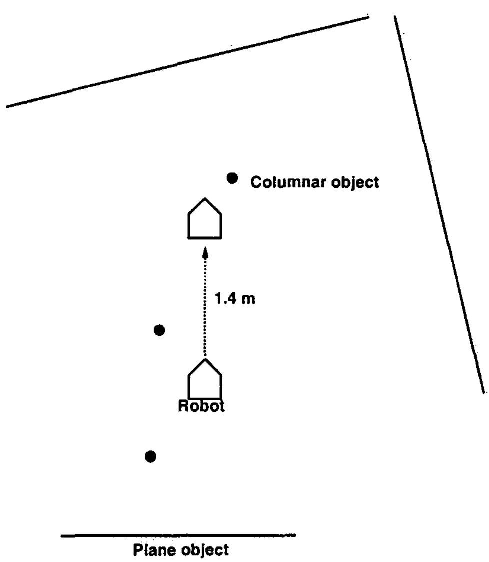

Figure 8: Scheme of experimental environment.

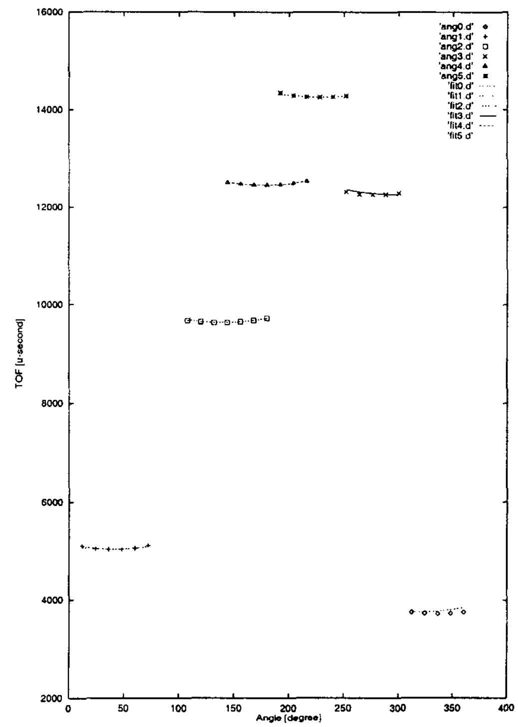

Figure 9: Leading edges which were detected by multiple receivers. Horizontal line shows bearing angle of receivers. Vertical line shows TOF.

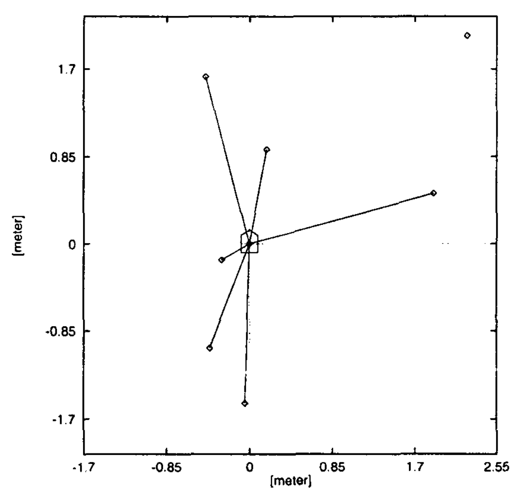

Figure 10: Calculated reflecting points from a single transmit/receive cycle.