Omnidirectional Ultrasonic Location Sensor

Akifumi NISHITANI
Tokyo Univ. of Science
2641, Yamazaki, Noda-shi,
Chiba, 278-8510, Japan
Email: a-nishitani@aist.go.jp

Yoshifumi NISHIDA
Digital Human Research Center, AIST
2-41-6, Aomi, Koto-ku, Tokyo,
135-0064, Japan
Email: y.nishida@aist.go.jp

Hiroshi MIZOGUCH
Tokyo Univ. of Science
2641, Yamazaki, Noda-shi,
Chiba, 278-8510, Japan
Email: hm@rs.noda.tus.ac.jp

Abstract— **Rapid construction of the human activity observation system at low cost is necessary with respect to research into human activities and commercialization. The authors have developed an ultrasonic 3D tag system that uses ultrasonic transmitters/receivers for observing human activities. The newly developed system monitors the positions of objects to which transmitters are attached. The ultrasonic 3D tag system can be installed in a wide variety of environments, but the time and the installation cost required to install the numerous required receivers are prohibitive. Therefore, the present authors developed an omnidirectional ultrasonic location sensor. The omnidirectional ultrasonic location sensor is useful because the number of sensors to be attached can be reduced. The present paper proposes an omnidirectional ultrasonic location sensor and reports its feasibility.**

I. Introduction

Recently, human-centered information processing services have been attracting increasing attention. The goal of the present research is to establish a technique by which to recognize both human activity and state in a living space. This requires human activity to be observed in real time, with high accuracy, and without the presence of restraints that prevent natural human activity.

As a method by which to realize efficient and robust recognition of human activities, the concept of object-based activity recognition has been proposed[1]. Theoretically, the behavior of handling objects in an environment such as an office or home can be recognized based on the motion of the objects. We have developed a three-dimensional (3D) ultrasonic location system as a fundamental system for robustly tracking objects and have verified that the observation of human activity based on object tracking is possible. However, like other location sensors, the developed ultrasonic location sensor has a disadvantage in that it is necessary to install numerous receivers in order to construct the ultrasonic 3D tag system in a wide variety of environments. This requires a great deal of time and the cost of installing a large number of receivers is high. Therefore it is difficult to collect activity data in the various environments in which actual human activities occur. Thus, we believe that the omnidirectional ultrasonic location sensor will be useful for reducing the time associated with sensor attachment.

The Bat Ultrasonic Location System [2], the MIT Cricket Indoor Location System [3], The Novel Broadband Ultrasonic Location System [4], and The DOLPHIN system [5] have been proposed as an ultrasonic location system. In contrast, the present paper puts an emphasis on quickly constructing the system at low cost. In this paper, we propose an omnidirectional ultrasonic location sensor that enables the 3D position of ultrasonic transmitters to be estimated over all azimuths, so that the time and cost of installing multiple ultrasonic location sensors is reduced. The user can easily construct a human activity observation system for field research on human activities.

II. Omnidirectional ultrasonic location sensor

Figure 1 shows an omnidirectional ultrasonic location sensor. The omnidirectional ultrasonic location sensor can not only receive the ultrasonic waves in an omnidirectional manner, can estimate the 3D positions of transmitters over all azimuths. An icosahedronn was then constructed by combining several equilateral triangle units. Each unit has three receivers in the vertex of each equilateral triangle. The three receivers on each unit are used for estimating 3D positions of transmitters.

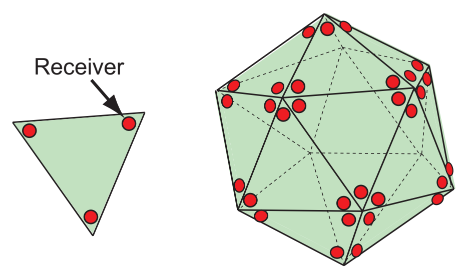

Fig. 1. Icosahedron to which receivers were attached

III. Simulation of measurement accuracy and measurable area

The required measurement accuracy and the required measurable area differ depending on the purpose and location of application. The development of simulation software that can calculate the measurement accuracy and measurable area for an omnidirectional ultrasonic location sensor beforehand would be useful. Measurement accuracy and measurable area simulation is performed and the results of the simulation are evaluated.

A. Simulation software of measurement accuracy and measurable area

In the simulation software, the measurement accuracy and the measurable area in a space can be shown for various numbers of receivers, the arrangement of the receivers, and sizes of the space. In the measurement accuracy simulation, an error margin whereby the standard deviation is 1.5 mm was added at random at each point. In the measurable area simulation, the directivity of the ultrasonic receiver was set to be 40 degrees.

B. Measurement accuracy simulation result

The measurement error was obtained by simulation when the side length of the equilateral triangle is changed. The simulation was performed for three side lengths of 70 mm, 150 mm, and 250 mm.

Figure 2 shows the simulation results for equilateral triangle side lengths of 70 mm, 150 mm, and 250 mm. The black spheres indicate the positions of the receivers. The difference in distance from the actual position of the transmitter is assumed to be the error. Table I shows the average error. When the side length becomes long, the measurement error is confirmed to decrease.

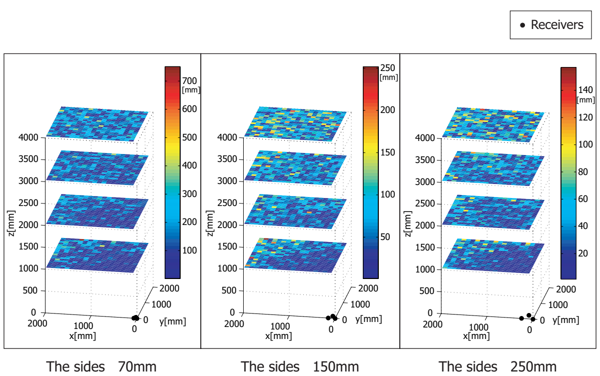

Fig. 2. Measurement error of simulation

TABLE I
AVERAGE ERROR OF SIMULATION

Side length	70mm	150mm	250mm
Average error	134mm	62mm	36mm

C. Comparison of actual measurement accuracy with simulation measurement accuracy

The simulation of measurement accuracy is compared with the actual measurement accuracy by motion capture to verify the validity of the simulation software. The accuracy is measured by arranging the receivers as the top of each equilateral triangle. Figure 3 shows the results of the actual measurement for equilateral triangle side lengths of 70 mm, 150 mm, and 250 mm. The receivers are placed on the origin. The x axis indicates the horizontal direction of the receivers arranged in the equilateral triangle, and the z axis is indicates the vertical direction of the receivers arranged in the equilateral triangle. The orange spheres indicate the actual positions as obtained by the motion capture, and blue spheres indicate the positions of ultrasonic transmitters. The difference in distance between positions of the motion capture and positions of the ultrasonic transmitter is error. Table II shows the average errors for each case. From Fig. 4, the measurement error is confirmed to decrease as the side lengths of the equilateral triangles become long, as is the case for the simulation results as well.

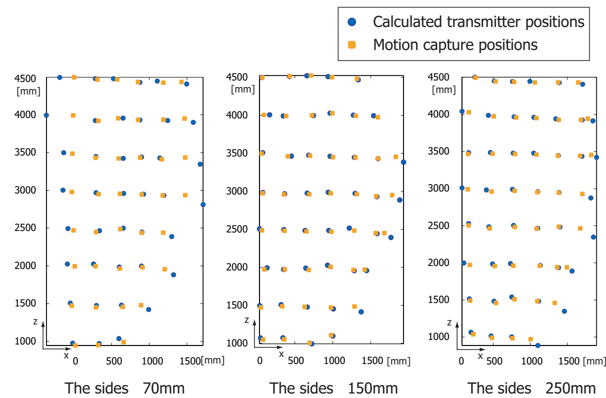

Fig. 3. Measurement error of actual measurement

TABLE II
AVERAGE ERROR OF ACTUAL MEASUREMENT

Side length	70mm	150mm	250mm
Average error	121mm	48mm	53mm

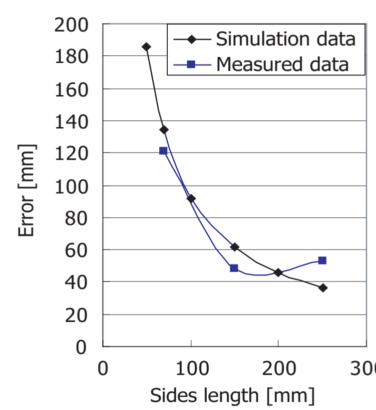

Fig. 4. Comparison of measurement errors of simulation and actual measurement

D. Measurable area simulation results

In the omnidirectional ultrasonic location sensor system, the transmitter is estimated by installing part of the omnidirectional ultrasonic location sensor, which consists of five equilateral triangle units, in the ceiling. Simulation of the measurable area is performed using the length of the side of the triangle of 100 mm. Figure 5 shows the results of the measurable area simulation for a height of 2 m for a $3 \times 3 \times 2.7$ m room. The measurable area of one equilateral triangle unit is indicated by the area shown in the same color as the equilateral triangle unit.

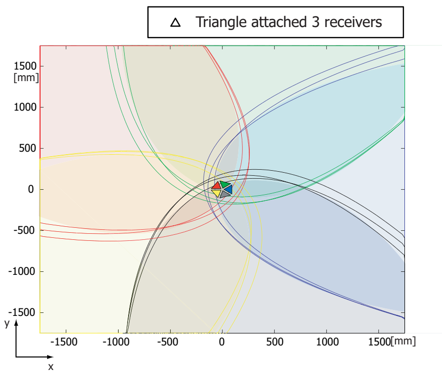

Fig. 5. Measurable area simulation

IV. Experiments

A. Prototype omnidirectional ultrasonic location sensor

Figure 6 shows a prototype omnidirectional ultrasonic location sensor. Three receivers are installed on each face of the icosahedron, the sides of which are 140 mm in length, and the distance between receivers is 100 mm.

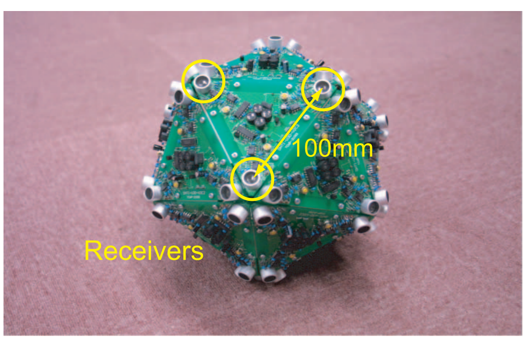

Fig. 6. Omnidirectional ultrasonic location sensor

B. Evaluation of measurement error and measurable area

The omnidirectional ultrasonic location sensor, which consists of five equilateral triangle units, is installed in the ceiling as a height of 3 m and the positions of the transmitter is estimated. One quarter of the whole area was measured. The rest assumed similar because of symmetry. Figure 7 shows the results of the measurable area of heights of 500 mm and 1,500 mm. The orange spheres indicate the positions as obtained by the motion capture, and the blue spheres indicate the positions of the ultrasonic transmitters. The average error is 108 mm and the standard deviation is 52 mm. Figure 8 shows the measurable area for a height of 0 mm. The experimental results indicate that the measurable area of the triangular unit is an ellipse having a major axis of 3 m and a minor axis of 1.2 m. Figure 9 shows the case in which the omnidirectional ultrasonic location sensor is installed in a 5×5 m room. The number of attached sensors is 36 in the case of current ultrasonic sensors, but the number of times that sensors must be attached is only three in the case of the omnidirectional ultrasonic location sensor. Thus the number of times that sensors must be attached becomes 1/12 that of previous systems.

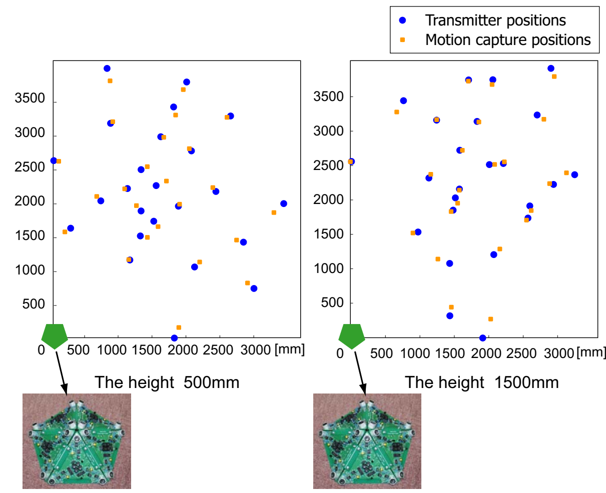

Fig. 7. Measurement error

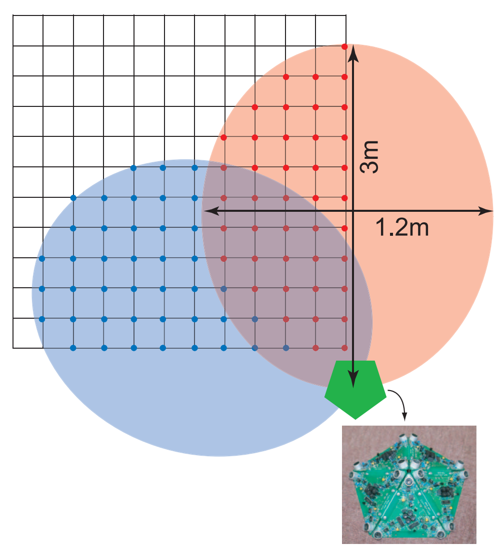

Fig. 8. Measurable area

V. Application

A system to estimate the position of a robot in a house is one application of the omnidirectional ultrasonic location sensor. Figure 10 shows a house in which a robot must approach an

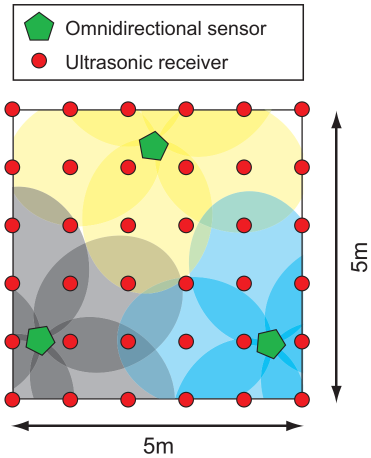

Fig. 9. Comparison of the number of attached receivers and the number of attached omnidirectionalsensors

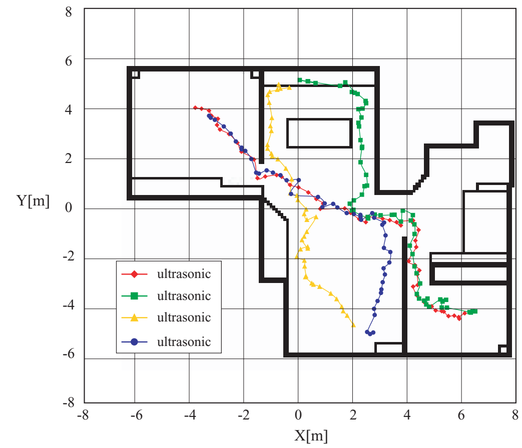

Fig. 12. Result of robot trajectory

individual in order to assist them. Thirteen omnidirectional ultrasonic location sensors that consist of five equilateral triangle units are installed on the ceiling of the house, as shown in Figure 11. The transmitters are attached to the robot, which can then estimate its own position and approach the person who has another transmitter. The position of the robot was measured by 203 points. Figure 12 shows the resulting robot trajectory. The total distance traveled by the robot was 53.425m, and the average error of measurement was 180[mm].

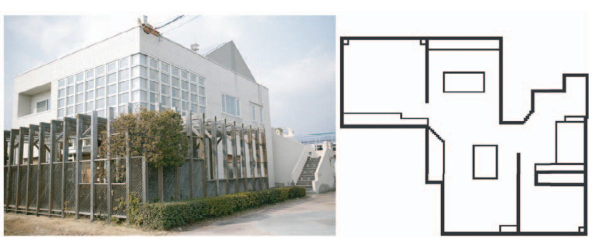

Fig. 10. Floor plan of a living space that must be navigated by a robot

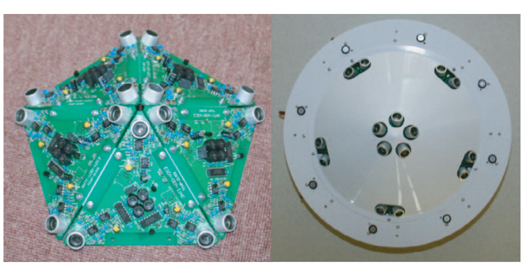

Fig. 11. Omnidirectional ultrasonic location sensors that consisting of five equilateral triangle units

VI. Conclusion

The present paper described an omnidirectional ultrasonic location sensor, which can estimate the 3D positions of transmitters over all azimuths and consequently reduce the installation cost for such systems. The proposed ultrasonic 3D tag system is low cost and easy to construct in various environments where actual human activities occur. The measurement accuracy for various distances between the ultrasonic receivers, which were arranged at the vertices of equilateral triangles that were arranged to form an icosahedral sensor, was simulated, and the simulation results were compared with the actual measurement accuracy. The measurable area was simulated. A prototype icosahedral omnidirectional ultrasonic location sensor, which combined three receivers arranged on equilateral triangle units was made. The experimental results showed that the average error was 108 mm for a distance between sensors of 100 mm and the measurable area per the triangular unit, was shown to be an ellipse having a major axis of 3 m and a minor axis 1.2 m for the case in which the omnidirectional ultrasonic location sensor was installed at a height of 3 m. The number of times that sensors must be attached for a 5×5 m room becomes 1/12 that of previous systems.

Acknowledgment

The authors wish to thank the KANSAI Electric Poewer co., Inc. for cooperation of experiments in a house.

References

[1] Y. Nishida, H. Aizawa, T. Hori, N.H. Hoffman, T. Kanade, and M. Kakikura, "3D Ultrasonic Tagging System for Observing Human Activity, " *in Proceedings of IEEE International Conference on Intelligent Robots and Systems (IROS2003)*, pp. 785-791, 2003

[2] A. Ward, A. Jones, and A. Hopper, "A New Location Technique for the Active Office," *IEEE Personal Communications, Vol.4, No.5*, pp. 42-47, October 1997

[3] N.B. Priyantha, A. Chakraborty, and H. Balakrishnan, "The Cricket Location-Support system," *in Proceedings of the 6th International Conference on Mobile Computing and Networking (ACM MobiCom2000)*, pp. 32-43, August 2000

[4] M. Hazas, and A. Ward, "A Novel Broadband Ultrasonic Location System," *in Proceedings of UbiComp 2002*, pp. 264-280, September 2002

[5] Y. Fukuju, M. Minami, H. Morikawa, and T. Aoyama, "DOLPHIN: An Autonomous Indoor Positioning System in Ubiquitous Computing Environment," *in Proceedings of IEEE Workshop on Software Technologies for Future Embedded Systems(WSTFES2003)*, pp. 53-56, May 2003