The Fourteenth International Symposium on Artificial Life and Robotics 2009 (AROB 14th '09),
B-Con Plaza, Beppu, Oita, Japan, February 5 - 7, 2009

Workspace mapping based on multi-sensor information fusion using heterogeneous onboard sensors

Masamichi Miyake, Hiroyuki Takai and Keihachiro Tachibana*

Graduate school of Information Sciences,
Hiroshima City University, Hiroshima, Japan
(Tel : 81-82-830-1628; Fax : 81-82-830-1792)
({miyake,takai}@sys.im.hiroshima-cu.ac.jp)

*Graduate school of Computer Science,
Osaka Gakuin University, Suita, Osaka, Japan
(Tel : 81-6-6381-8434)
(tatibana@ogu.ac.jp)

Abstract: In recent years, multiple robot systems that perform team operations have been developed. These robot systems are expected to execute complicated tasks smoothly in a given congested workspace. In this paper, we propose a workspace mapping algorithm using ultrasonic stereo sonar and an image sensor in order to operate the mobile robots among obstacles. This workspace mapping algorithm involves two steps: 1) the position detection of obstacles using ultrasonic stereo sonar and 2) the shape detection of obstacles using an image sensor. While each robot moves around in the given workspace, the two steps of the mapping algorithm are repeated and sensor data are collected. The robot measures the distance and the direction of obstacles using ultrasonic stereo sonar. The shape of obstacles is also captured using an onboard image sensor. A workspace map is created based on the sensor data accumulated from the proposed method and successful results are also obtained through the experiments.

Keywords: autonomous mobile robot, navigation system, localization, map creation, ultrasonic signal processing, **.**

I. INTRODUCTION

In the last several years, multiple mobile robot systems that perform team operations have been studied. These robot teams are expected to execute complicated tasks such as USAR (urban search and rescue) operations and/or repairing industrial facilities in hazardous environments.

When the number of robots increases in the same workspace, the occurrence of collisions also increases. We think that one of the causes of the collisions is related to the mutual position among the robots and/or the arrangements of the obstacles in the workspace. If the robots follow a plan that is created based on an exact workspace map, they should be able to avoid some of the collisions. In order to decrease the chance of collisions, the robots collect positional information of obstacles in the workspace and share a workspace map that is created from the sensor data.

In order to create and share the workspace map, the robots have to share the global coordinate axis and the point of origin. However, if the robots are operating in an unknown workspace, since there are no artificial landmarks prepared previously, they have to find and choose an obstacle of particular shape in the workspace to position their point of origin. In order to confirm fundamental principles of this map creation method, we have considered an ideal workspace to be a place where the floor is flat and all objects stand perpendicular. This ideal workspace is similar to most buildings where there are many walls and pillars resting on a flat floor. In addition, some of the walls and pillars create "corners (concave) / edges (convex)" in the workspace. As a result, these "corners / edges" can be used as temporary reference points that become candidates for the point of origin in the workspace, since they are easy to detect using onboard sensors.

In order to create the workspace map, the positional information of obstacles uses the Cartesian coordinates as the positional information needs to be normalized. On the other hand conventional sensors output positional data that centers the robot and indicate the distance and the direction from the robot. Therefore, the robot that is creating a workspace map has to transform the coordinates system of the positional information from polar coordinates to Cartesian coordinates. In addition, when the robot moves around in the workspace, since the center position of the detected positional data has been changed, the map-creating robot needs to repeat the transformation of its coordinate systems.

We propose a workspace map-creation algorithm using ultrasonic stereo sonar and an image sensor with a laser line generator. Ultrasonic stereo sonar can measure the distance and the direction of objects at the same time using a simple signal processing algorithm. The image sensor with a laser line generator can take a geometrical feature of the object also using simple image processing algorithms. We have considered a method of compiling of positional information detected by both onboard sensors in order to improve the accuracy of map creation.

II. Multi-obstacles position detection algorithm using ultrasonic stereo sonar

1. Distance measurement using ultrasonic sonar

Ultrasonic sonar is one of the major onboard sensors for mobile robot systems. Conventional ultrasonic sonar detects the envelope of the received signal and measures the time period until the envelope exceeds a threshold of signal strength from the ultrasonic emission. However, since the threshold of this method is defined empirically, it has incomplete theoretical background and is mostly guess work. Therefore, this measurement method is slightly flawed.

Another method of distance measurement using ultrasonic sonar measures the time period from when the ultrasonic pulse is emitted until the peak of the envelope of the received signal is reached. However, the peak of the envelope indicates the distance of the maximum reflective cross section and it does not represent true distance.

We examined a signal processing algorithm that estimates the true distance from the received reflected ultrasonic signal. Figure 1 shows a model of time period estimation algorithm. In figure 1, the horizontal axis is time and the vertical axis is amplitude. Several data sets of time and amplitude are measured and then regression lines p and q are computed based on the measured data sets using the least-square method. The intersection of regression lines p and q shows the estimated period t. The distance is derived from the estimated time period t based on the acoustic velocity.

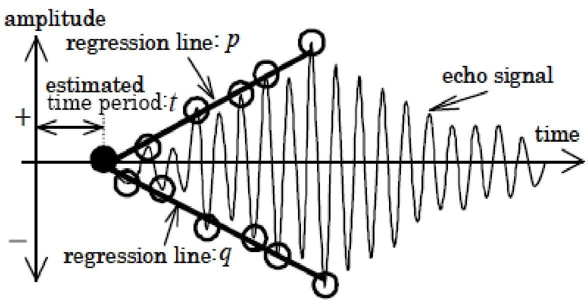


Fig. 1 A model of time period estimation

2. Direction detection using ultrasonic stereo reception

In order to scan surrounding obstacles, conventional ultrasonic sonar needs to rotate mechanically because it receives monaural signals and only measures distance from one frontal point. When the robot moves, and if the sonar also rotates, it may lose the position of obstacles and increase the possibility of collisions. In addition, it is difficult to downsize a mechanical rotator for ultrasonic sonar and to define its scanning width and scanning speed.

We examined ultrasonic stereo reception that receives reflected signals using two ultrasonic microphones. When the beam width of the ultrasonic device is wide, ultrasonic waves spread out not only in front of the device but also to the left and right sides. Two ultrasonic microphones of stereo reception receive the reflected signal that have time differences because the signal is reflected by an obstacle positioned in the left or right side and the distances from the obstacle to the microphones are different. In this method, the distances and the directions of the obstacle can be measured from the time of arrival (ToA) and the time difference of arrival (TDoA) of the received signal. Figure 2 shows a model of ultrasonic stereo reception.

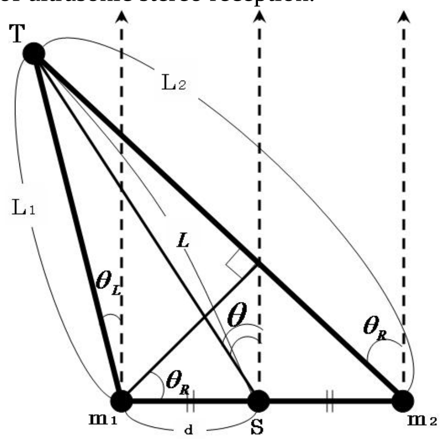


Fig. 2 A model of ultrasonic stereo reception

The parameters in figure 2 indicate below.
T: the position of an obstacle,
S: the position of an ultrasonic speaker,
m_1, m_2 : the position of the left / right microphones,
L : the distance from the speaker to the obstacle,
L_1,:the distance from the obstacle to the left microphones,
L_2 :the distance from the obstacle to the right microphones,
θ : the shift angles from the speaker,
θ_L, θ_R : the sift angle the left / right microphone,
d: the intervals between the speaker and microphones.

When the distance L_2 is greater than L_1, the distance L and the direction θ of are calculated by the equation 1. The distance L_1 and L_2, the direction θ_L and θ_R are positioned opposite if the distance L_1 is less than L_2.

$$\theta_R \propto \frac{L_2{}^2 - L_1{}^2 + 4d^2}{4dL_2}$$

$$\theta \propto \frac{L_1 \sin\theta_L + d}{L_1 \cos\theta_L} \qquad (1)$$

$$L \propto \frac{L_1 \cos\theta_L}{\cos\theta}$$

III. Obstacle direction detection using image processing

We examined a laser line generator that can draw a straight line on a flat surface as an extra light source for an image sensor. When the laser line generator illuminates an object, an image sensor can capture a visual representation of the geometric features of the object. In order to detect the location and direction of the object, the shape of the object is extracted from the captured image using image processing algorithms. Figure 3 shows an extraction model with reference point using an image sensor.

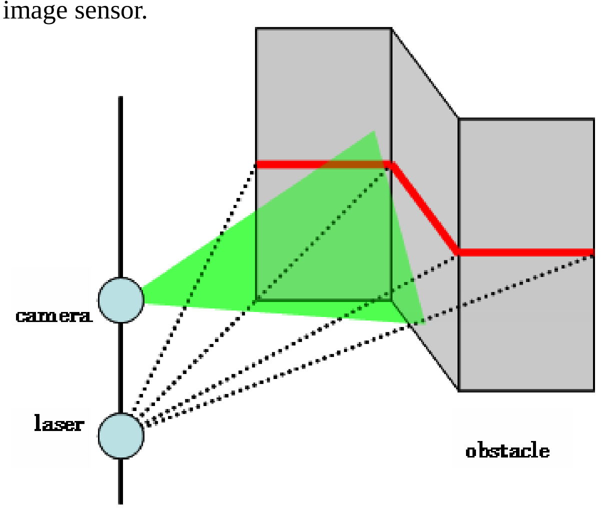
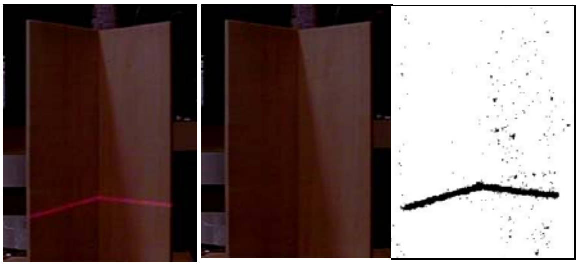


Fig.3 Extraction model with reference point using an image sensor

The shape of an obstacle is calculated by taking the difference between the captured images and background images. Figure 4 shows an example of shape detection using difference image processing. The position of the corner / edge can be calculated from the vertexes of kinked lines that are detected from the difference image.



(a) captured (b) background (c) difference

Fig.4 A shape detection using difference image processing

IV. Workspace map creation algorithm

In order to represent an arrangement of objects in the given workspace, we have proposed a map creation algorithm based on the captured sensor data using ultrasonic sonar and image sensors. This has been modified from our previous research [1]. The procedure of the map creation is shown below.

(1) A robot detects the position of neighboring obstacles using ultrasonic stereo sonar.

(2) The robot illuminates obstacles using a laser line generator and captures features of the shape of each obstacle using image sensors.

(3) If a kinked line is detected in the captured image of the geometrical special feature of the object, since "an edge" or "a corner" of the object is mapped onto the image as in the vertex of the kinked line, the map creation algorithm calculates the position of "the edge" or "the corner" as a temporary reference point. Conversely, if a straight line is detected in the captured image, since "a flat surface" of the object is mapped onto the image as in the straight line, the map creation algorithm interprets it as a part of "the flat surface" of the object.

(4) Positional information of a temporary reference point detected by sensors needs to be converted from polar coordinates into a Cartesian coordinates.

(5) The positional information of the temporary reference point detected by sensors needs to be transformed into global coordinates, since the local coordinates of the robot shift along with the motion of the robot.

(6) The positional information of the temporary reference point that was transformed into the global coordinates is compared with the latest workspace map. If the positional information of the reference point has not been registered in the map yet, it is added into the map and the map is then updated.

(7) The robot repeats steps from (1) to (6) as it moves and updates the map.

VI. Exploratory experiment

We examined the performance of ultrasonic stereo reception. Figure 5 shows three targets in an experimental field. In this figure, ultrasonic speaker and microphones are placed in the left side of the field. In this experiment, Murata MA40B8R/S (Carrier frequency: 40 KHz, Beam width: 50 degrees) is used as the ultrasonic devices.

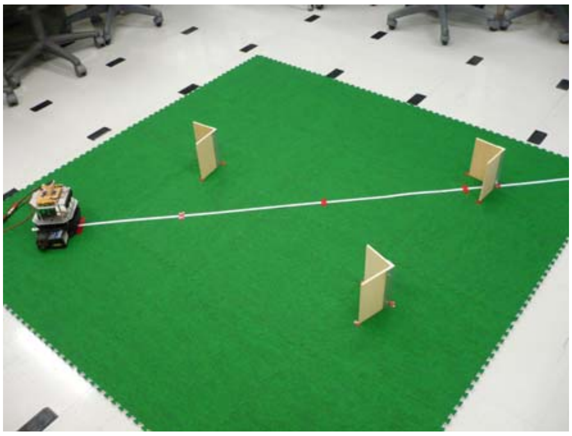


Fig.5 An experimental field with three targets

Figure 6 shows a sample of reflected ultrasonic signals. In figure 6, three target echoes can be found in these received signals. Table 1 shows the experimental results derived from ultrasonic stereo sonar. In this table, the positional information indicated the distance and the direction can be measured using ultrasonic stereo sonar.

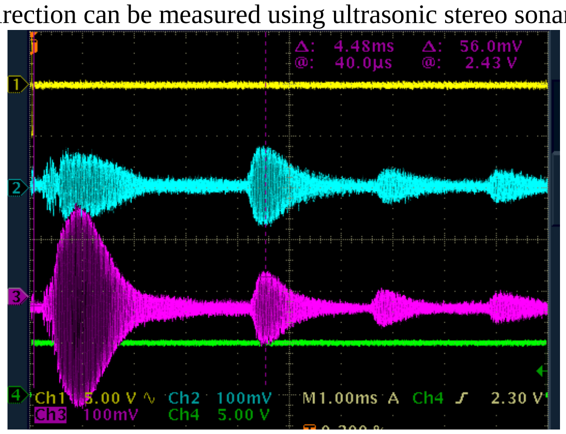


Fig.6 Echoes from the three targets

Table 1. Measurement results of ultrasonic stereo sonar

	Target 1		Target 2		Target 3	
	Distance	Angle	Distance	Angle	Distance	Angle
Theoretical	715.9	24.8L	1118.0	26.6R	1500.0	0.0
Trigger	701.2	21.6L	1094.4	26.4R	1502.5	2.4L
Error (Trig)	-14.7	-3.2	-23.7	-0.2	2.5	2.4
Burst	701.0	20.5L	1128.3	28.2R	1512.1	0.3L
Error (Burst)	-14.9	-4.2	10.3	1.7	12.2	0.3

Unit: distance (mm), angle (degree)

V. Conclusion and Future works

We proposed the ultrasonic stereo sonar system and the target position estimation algorithm using the least-square method. The performance and the accuracy of the target position estimation algorithm were confirmed through the exploratory experiments.

We also proposed the map creation algorithm that was modified from our previous research [1]. The previous algorithm used ultrasonic monaural sonar and the results of its position estimation were inaccurate due to the difficulty of collating to the same coordinate axis given by the ultrasonic sonar and image sensors. The modified algorithm that is proposed in this paper uses ultrasonic stereo sonar and the algorithm can collate the same coordinate axis because both sensors can measure the direction. Figure 7 shows a sample of the workspace map [1].

In future works, these algorithms will be installed into the small mobile robots and workspace maps will be created using these algorithms. We will confirm the accuracy of these algorithms through the workspace map.

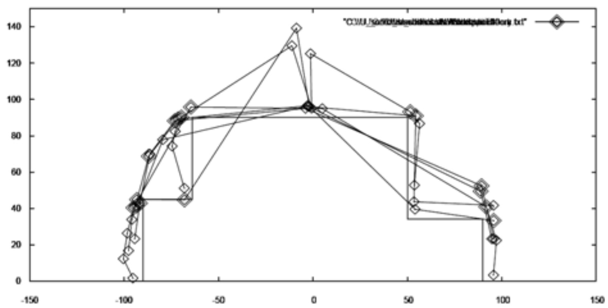


Fig.7 A sample of the workspace map

REFERENCES

[1]H. Takai, J. Mitsuoka, et, al. (2006): “Feasibility study of Sensing Methods on Cooperative Localization for Team Operation of Multiple Mobile Robots”, The3rd International Conference on Autonomous Robots and Agents (ICARA2006) pp.379-385, Palmerston North, New Zealand, 2006

[2]H. Takai, M. Miyake, et, al. (2008): “Multi-Robot Cooperative Localization and Mapping using Multi-Sensor Information Fusion” Proceeding of the 39th ISR (International Symposium on Robotics 2008) pp.342-347, Seoul, Korea, 2008