Acquisition of an Environmental Map by Sonar Data for an Autonomous Mobile Robot with Web Interface

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Abstract: A method for acquiring an environmental map by integrating distance data obtained by sonars of a moving robot with web interface is proposed. Sonar data contains outliers in some cases such as ultrasonic beam is projected onto a corner of an object. Therefore, the influence of the outliers should be reduced by detecting outliers. In our method, the outliers are detected by two ways: (i) a method considering geometrical relation among the observed surface and the projected ultrasonic beam, and (ii) a method considering consistency with data obtained by other sonars. By measurement by the sonar, the distance from the sonar to the obstacle is obtained. Assuming the two dimensional space, we can know that the inside of the sector, whose center coincide with the sonar and whose radius is equal to the obtained distance, is the free area, and a part of the arc of this sector is the obstacle area. The generation of the environmental map is done by integrating the free area and the obstacle area obtained by each measurement by the sonars. Before the integration, the outliers detection is done by two ways mentioned above. Experimental results show that obtained maps obtained by our methods with outliers detection are much better than those by a method without outliers detection.

1. Introduction

We are developing the system for manipulation the autonomous mobile robot with web interface. To realize such the system, many functions should be implemented to the robot for autonomous movement such as the obstacle avoidance, the acceleration control, the generation of the environmental map[1], [2], [3], the localization of the robot[4], or the path planning[5], etc. In this paper, we especially present a method for generation of an environmental map by the distance data obtained by sonars of the robot exploring an unknown environment.

Sonars are utilized for mobile robots because they are safe, cheap, lightweight, and can detect range data directly. But sonar data contains outliers in some cases such as ultrasonic beam is projected onto a corner of an object. Such the outliers are sometimes larger than the actual distance. Therefore, it should be detected the outliers and reduced the influence of the outliers in the generation of the environmental map to realize the safety movement of the robot. In our method, we applied two methods for the detection of outliers: a method considering geometrical relation among the observed surface and the projected ultrasonic beam, and a method considering consistency with data obtained by other sonars.

There are many methods to deal with the outliers of the distance data obtained by a sonar for the generation of the environmental map[1], [2], [3]. The characteristics of our method is simplicity in the treatment of the obtained data and the generated map.

2. Autonomous mobile robot with web interface

The robot used in this research is "B14R" by the Real World Interface shown in Fig.1. This robot has 16 sonars, and a camera. The OS of this robot is Linux with HTTP server.

Figure 1. The robot used in this research, "B14R" by RWI. This robot has 16 sonars.

Using this robot, the system for manipulation the autonomous mobile robot with web interface is developing. Besides the generation of the environmental map described in this paper, functions for autonomous movement is now being implemented to this robot such as the obstacle avoidance, the acceleration control, and the path planning, etc.

The overview of this system is shown in Fig.2.

3. Distance obtained by a sonar

The robot B14R has 16 sonar arranged at the same height. Therefore, two dimensional map of this height is generated. The environmental map is built using distance data obtained by 16 sonars of the mobile robot.

The principal of the distance measurement of the sonar using this research is so-called "time-of-flight" principal. It projects ultrasonic beam onto the measured object and calculate the distance from the sensor to the object from the time until the reflected beam

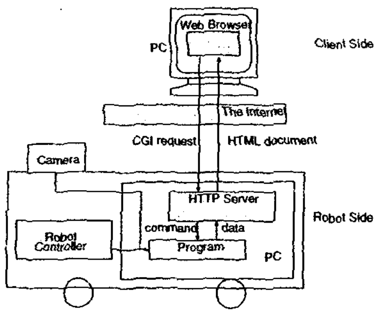

Figure 2. Overview of the system for manipulation the autonomous mobile robot with web interface.

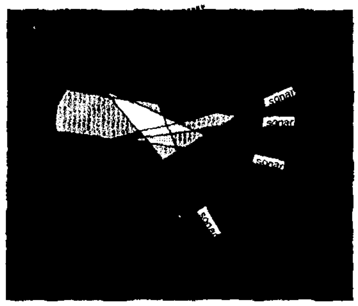

Figure 4. The free area and the obstacle area obtained by integrating the data obtained by many sensors and at many positions.

returns. Assuming the two dimensional space as mentioned above, the projected beam spread as shown in Fig.3. By one measurement of one sonar, inside area of this sector is free and the obstacle exists on the arc (or a part of the arc) of this sector. As the distance is larger, the ambiguity of the obstacle area increase because the arc length of this sector becomes long.

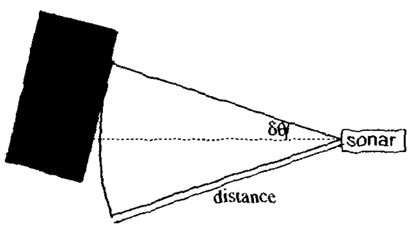

Figure 3. The distance measurement by a sonar. It is known that the inside area of this sector is free and the obstacle exists on the arc (or a part of the arc) of this sector.

It should be noted that the sonars give rise to some kind of errors specially when the projected beam is reflected at the corner of the measured object, or the projected beam is nearly parallel to the measured object. Especially, it is serious problem for the safety movement of the robot when outliers of the distance data are larger than the real distance. To deal with such outliers of the data, two methods for detection of outliers are applied: a method considering geometrical relation among the observed surface and the projected ultrasonic beam described in Sec.5.1, and a method considering consistency with data obtained by other sonars descried in Sec.5.2.

4. The environmental map

As mentioned above, the inside area of the sector in Fig.3 is free and the obstacle exists on the arc (or a part of the arc) of this sector by one measurement. The environmental map is built by integrating the free area and obstacle area obtained by many sonars and at many positions of the robot moving around the unknown environment.

The value of each cells of the environmental map equal to 0 if they are in the unknown area, have positive values if they are in the free area, and have negative values if they are in the obstacle area. Such the map is generated by the processes mentioned below: First, the values of all cells are initialized to 0. For each sonars at each positions, the values of the cells at the inside area of the sector in Fig.3 are increased and the value of the cells on the the arc of this sector are decreased. By repeating these processes for each distances obtained by many sonars and at many positions of the robot, the absolute values of each cells become positively and negatively large if the possibilities of being in the free and obstacle are high, respectively.

In these processes, the problem is to reduce the influence of the above mentioned outliers of distance data obtained by sonars. We employ two methods for outlier detection to reduce the influence of the outlier: a method considering geometrical relation among the observed surface and the projected ultrasonic beam and a method considering consistency with data obtained by other sonars. If the obtained distance is detected as the outliers, the absolute value of the increase and decrease value of the cells are reduced.

4.1 Generation of the map

In this section, the algorithm for building the environmental map is described.

First, the values of all cells are initialized to 0. For distance $d_n(t)$ obtained by the n-th sonar at the time t, the values of the cells at the inside of the sector whose center coincide with the the n-th sonar at the time t, whose radius is equal to $d_n(t)$, and whose vertical angle is equal to $2\delta\theta$, is increased by $C_f(t,n)$, and the value of the cells on the the arc of this sector are decreased by $C_o(t,n)$. The incremental and decremental values $C_f(t,n)$ and $C_o(t,n)$ are determined by detecting the outliers and considering the ambiguity of the obtained distances.

$$C_f(t,n) = I(t,n)\ u(d_n(t))\ p \quad (1)$$

$$C_o(t,n) = I(t,n)\ u(d_n(t))\ q \quad (2)$$

$$I(t,n) = \begin{cases} \varepsilon(0<\varepsilon<1), & \text{distance from } n\text{-th sonar at the time } t \text{ is assumed to be the outlier} \\ 1, & \text{else} \end{cases} \quad (3)$$

where p and q are constants, $u(d)$ equals to 1 if $d \leq$

D_H(D_H is the threshold) and is monotonically decreasing function if $d > D_H$ whose value is $0 < u(d) < 1$.

Two methods employed for outlier detection are described in the following sections.

5. Outlier detection

5.1 The geometrical relation among the observed surface and the projected ultrasonic beam

As mentioned in Sec.3. in the measurement by the sonars used in this research, the accurate distance is obtained when the projected ultrasonic beam is nearly perpendicular to the object, while the obtained distance is the outlier and quite different from the true distance when the projected beam is reflected at the corner of the object, or the projected beam is nearly parallel to the object.

Therefore, to detect such outliers, the angle between projected beam and the object is estimated and used for the detection of the outliers. The angle between projected beam and the object is estimated by two successive distances as shown in Fig.5. If the estimated angle θ is outside the range of $(90-\delta\theta) < \theta < (90+\delta\theta)$, the obtained distance is assumed to be the outlier.

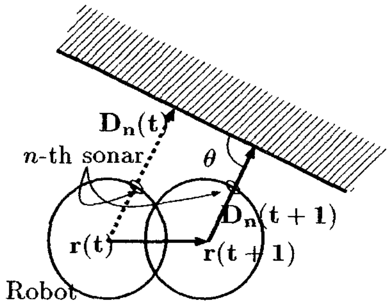

Figure 5. The angle θ between projected beam and the object estimated by two successive distances. If θ is not nearly equal to 90 degree, the obtained distance is assumed to be outlier.

5.2 The consistency with data obtained by other sonars

The detection method described in Sec.5.1 successive outliers can not be detected as outliers. For example, when the ultrasonic beam is projected onto the concave corner of the object, the configuration of the projected beam and the object after the movement of the robot is almost the same as that before the movement as shown in 6. Thus, the consistency with distance data obtained by other sonars are used for the detection of outliers. For the distance at the time t, the consistency with the map generated by the distances obtained at the time 0 to $t-1$ is used.

For the distance $d_n(t)$ obtained by the n-th sonar at the time t, if $|d_n(t-1) - d_n(t)|$ is larger than the threshold or the $d_n(t-1)$ is assumed to be the outlier, the values of the cells passed by the segment, whose

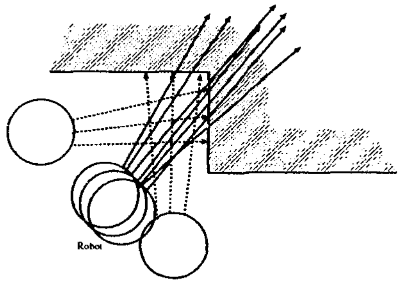

Figure 6. The successive outliers. When the ultrasonic beam is projected onto the concave surface, the configuration of the projected beam and the object is almost the same after the movement of the robot.

begining point is the position of the n-th sensor,whose direction is the same as the projected beam, and whose length is $d_n(t)$, is examined. If there are any cells whose value is smaller than the threshold, $d_n(t)$ is assumed to be the outlier.

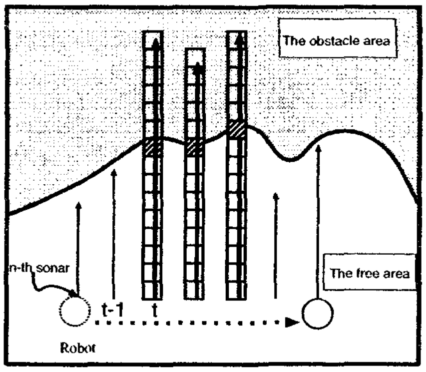

Figure 7. The reference of the map built using the distances already obtained by the other sonars. If the distance at the time t is not consistent with the map built using the distances obtained between the time 0 to $t-1$, it is assumed to be the outlier.

Of course, at the begining of the map generation, the environmental map has not enough information to detect the outliers. This method is not applied at the begining.

6. Experimental results

In this section, the result of the map generation by the method described above. The two experimental environments were shown in Fig.8.

The results for the environment shown in Fig.8(a) is shown in Fig.9 and those for the environment shown in Fig.8(b) is shown in Fig.10. In these figures, the free area is expressed with white and the obstacle area is expressed with black.

In the Fig.9 and Fig.10, (1)'s are the map built by integrating sonar data without any outlier detections, (2)'s are the map built with only one outlier detection described in Sec.5.1 (3)'s are the map built with only one outlier detection described in Sec.5.2 and (4)'s are the map built with both outlier detections.

As shown in Fig.9 and Fig.10, in the maps (1) built without outlier detections, there are many areas expressed by white even if the obstacle areas in the actual environment shown in Fig.8. The maps (2) and (3) built with only one outlier detection are better than the maps (1) without outlier detections, but yet many obstacle areas in the actual environment are expressed as the free area. The maps (4) built with both outlier detections are much better than other results. From these results, our two outlier detection methods are effective for the generation of the environmental map and the generated maps with our outlier detection method express the actual environment much better than maps without outlier detection.

7. Conclusion

In this paper, a method for generation of an environmental map by integrating distance data obtained by sonars of a moving robot with web interface was proposed. Sonar data contains outliers in the case when the ultrasonic beam is projected onto a corner of an object. To reduce the influence of the outliers, we applied tow methods for detecting outliers: a method considering geometrical relation among the observed surface and the projected ultrasonic beam, and a method considering consistency with data obtained by other sonars. Experimental results shows that two outlier detection methods are effective for the generation of the environmental map.

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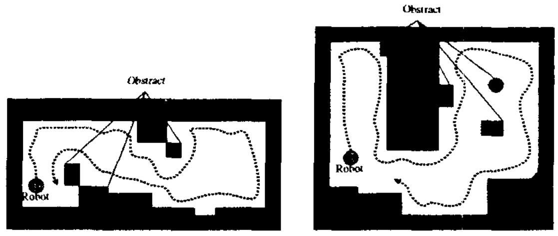
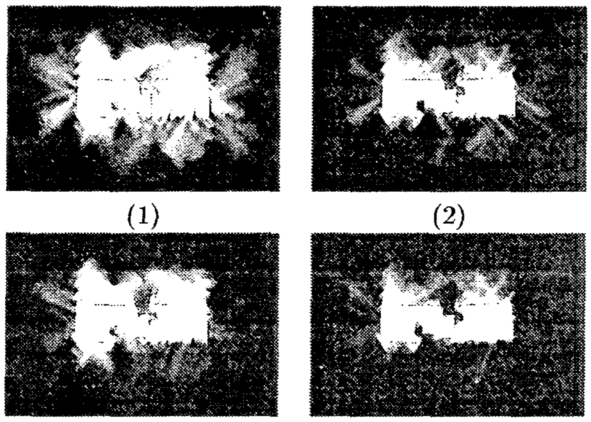


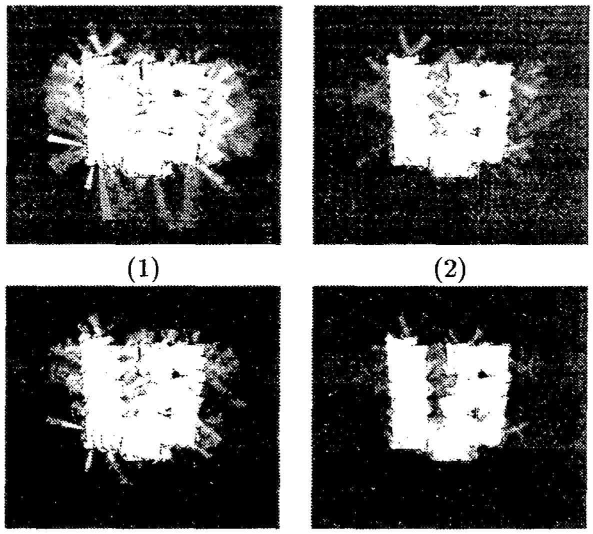
(a) (b)

Figure 8. Two experimental environments.



(1) (2) (3) (4)

Figure 9. The results for the environment shown in Fig.8(a). (1) The map built by integrating sonar data without any outlier detections. (2) The map built with only one outlier detection described in Sec.5.1. (3) The map built with only one outlier detection described in Sec.5.2. (4) The map built with both outlier detections.



(1) (2) (3) (4)

Figure 10. The results for the environment shown in Fig.8(b). (1) The map built by integrating sonar data without any outlier detections. (2) The map built with only one outlier detection described in Sec.5.1. (3) The map built with only one outlier detection described in Sec.5.2 (4) The map built with both outlier detections.