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Fusion of Omni-directional Sonar and Omni-directional Vision for Environment Recognition of Mobile Robots

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Abstract

This paper propose a new method of sensor fusion of an omni-directional ultrasonic sensor and an omni-directional vision sensor. A new omni-directional sonar, which we developed, can measure accurate distance and direction of reflecting points, and an omni-directional vision can give direction to edges of segment. We propose a sensor fusion method using both the reflecting points measured by the sonar and the edges of segment measured by the vision, based on the angles. Those data are different in character, so they compensate each other in the proposed method, and it becomes possible to get better information which are useful for environment recognition of mobile robots. We describe the proposed method and an experimental result to show its potential.

1 Introduction

An external sensor is essential for a mobile robot to respond to its surrounding environment and determine its position. There are many requirements for the external sensor. First of all, accuracy is important, and wider view are necessary for avoiding collision and for faster motion [1]. For achieving better environment recognition, sensor fusion is a one of the effective way [2]. However, each sensor must have sufficient capability to achieve the most efficient environment recognition [3].

An ultrasonic sensor is the most popular sensor for indoor mobile robots, because it is simple and gives distance information directly. Generally, the ultrasonic sensor was known as it has a big problem that it is difficult to measure accurate direction [4]. However, recently we have developed an omni-directional sonar which can achieve accurate direction measurement [5]. The new omni-directional sonar can get accurate direction and distance information of reflecting points all around the robot in a single measurement. Consequently, it became possible to measure accurate environmental information including distance. But unfortunately, those reflecting points can be obtained only sparsely, hence they are insufficient to know entire feature of the environment.

Vision sensors are getting used for mobile robots easily because of recent improvement of cameras and processors. And also, a special mirror attaching to a camera was developed and it became easy to get omni-directional view from a single image [6]. The omni-directional image can provide segment information of the environment around the robot. However, it is difficult to know distance information of the environment from the image, hence no information about shape of the environment can be given.

In this paper, we propose a simple sensor fusion method of the omni-directional sonar and the omni-directional vision for an indoor mobile robot using their strong points; the sonar can measure distance and the vision can provide segment information. The new sonar, which we developed, can give accurate positions of reflecting points, and the vision can provide edges of segment in the environment. Both of those sensors can measure omni-direction in a single measurement, and they can get accurate angles. Thus we propose a fusion method using their angles as the key to connect them. Because those data are different in characteristics, they compensate each other in the proposed method, accordingly it become possible to get better feature of the environment which are useful for environment recognition. And also, the omni-directional sonar and the omni-directional vision have wide view, all around the robot, in a single measurement, that is very useful for a mobile robot navigation. Consequently, more accurate and denser information can be gotten by the fusion, even in a single measurement process.

In the next section, we propose a method to fuse omni-directional sonar data and omni-directional vision data. An experiment in a normal passage environment for a mobile robot was performed to verify the potential of the proposed method, and the experiment and its result are described in Section 3. And then, we discuss the method and possible applications.

2 Fusion of vision and sonar

2.1 Omni-directional sonar

Many objects in indoor environments can be assumed to be specular reflectors for ultrasonic waves, since wave length of ultrasound used in air are from 4mm to 20mm. Specularity implies that the reflection comes from a point, not from an area, and that the reflecting position is on surface of the wall which is perpendicular to the incident direction of a plane or curved surface, or a convex corner [7]. Hence, if we can measure the accurate direction of the reflecting point, useful information such as bearing angle of the wall, or positions of edge or corner can be gotten.

It is known that accurate direction measurement to the reflecting object is not easy for conventional ultrasonic sensors because of its wide directivity, which are about 30 $\sim$ 60 degrees. However, it is possible to accomplish accurate direction measurement employing multiple receivers and using those propagation time differences of leading edges of the echoes which are coming back from the same reflecting object.

We have developed a new omni-directional sonar which can measure accurate direction to the reflecting points all around the robot simultaneously [5]. This omni-directional sonar can measure accurate distance and direction to corners and edges, and the nearest points on plane reflectors, which consequently shows perpendicular to the incident direction of the plane surface. However, those reflecting points measured in a single measurement are sparse data in the environment, and they are insufficient to know entire feature of the environment (Fig.1(a)).

2.2 Omni-directional vision

An image which is gotten by a single camera is the same image as you can see when you close a single eye. That means, it is a picture of environment which does not include distance information.

Most of the indoor environment are constructed by combination of uniform planes, and it is possible to detect edges of wall segment in the environment from a single measurement by vision. Thus vertical edges are useful special feature in the environment, for example corner, edges, doors and so on. However, it is difficult to know distance information of them in the environment, therefore it is hard to know shape of the environment (Fig.1(b)).

In case of using omni-directional vision sensor, though its resolution goes low, all environment around the robot are able to obtain in a single image [6]. Consequently, it became possible to know relative directions of the special features.

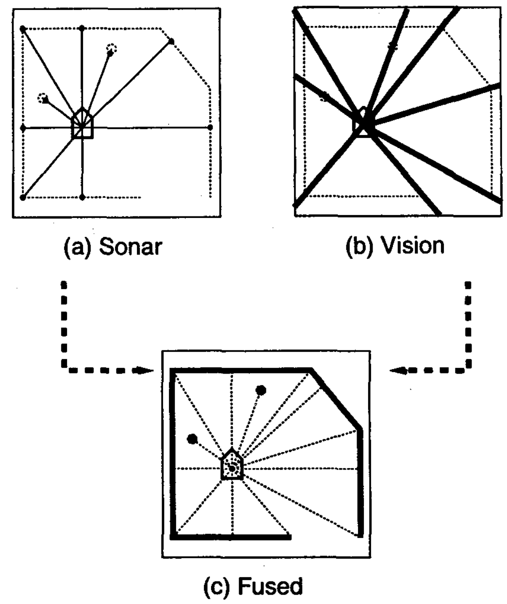

Figure 1: Conceptual scheme of sensor data fusion of the omni-directional sonar and the omni-directional vision. (a)The new omni-directional sonar provide accurate reflecting points including distance and angle, but those points are sparse. (b)The omni-directional vision provide direction of edges, but they do not include distance information. (c)Fusing those data based on the direction, it become possible to know feature of the environment.

2.3 Fusion

Here, we propose a simple sensor fusion method of the omni-directional sonar and the omni-directional vision. Those sonar and vision information can complement each other based on the directional informations. Therefore the fusion makes it possible to do much better environment recognition.

As explained before:

- The omni-directional sonar can provide directions and distances to edges, corners and reflecting points at plane surface, which is perpendicular to the incident direction of the plane.
- The omni-directional vision can provide directions to edges of wall segment in the environment. That means a vision can provide the information of continuity radial direction of the environment.
- The omni-directional sonar sensor, which we developed, can give accurate directional information, and the omni-directional vision sensor also can give directional information.

Considering those points, detected reflecting points in sonar and detected edges in vision are fused to give environmental feature information based on the direction with following methods:

- If an edge in vision exists around the direction of a reflecting point in sonar, the reflecting point is considered as an edge or an corner in the environment, and it is remained as a point.
- If there is no edge in vision around the detected reflecting point in sonar, the reflecting point is considered as it is on a plane surface. Therefore, a line which lies on the reflecting point and perpendicular to the direction of the reflecting point is drawn between the bearing angles of the nearest two edges in vision, in left and right side respectively.

This is based on the assumption that the environment is structured by flat plane surfaces as like a wall, and the physical property that the reflecting point of sonar exists incident direction of the plane. As the result, features of environment can be gotten as shown in Fig.1(c).

3 Experiment

An experiment was performed to know the potential of the proposed method in real environment as shown in Fig. 3.

3.1 Experimental setup

The mobile robot with a sonar and a vision sensor used in this experiment is shown in Fig.2. We mounted a omni-directional mirror [8] and camera (EVI-330,SONY) on the top of the robot. Our developed omni-directional sonar which can measure accurate direction is placed under the camera [5]. The size of the sonar-ring is 29cm in diameter and 30 transducers are placed on the circumference, which is 16cm in diameter and is 50cm in hight from the ground.

3.2 Sonar process [5]

In our developed omni-directional sonar, transducers are placed on the circumference intimately and all transmitters are driven simultaneously by a transmission signal about 270V wide band pulse. Consequently it can be assumed as being emitted by a single point source located at the center in two dimensions. Then, 30 receivers on the circumference which are connected to individual amplifiers receive echoes simultaneously for calculating accurate direction from time-of-flight difference. The amplified received wave signals go through comparators with a threshold value. The outputs of the comparators which are binary signal per receiver are sampled and stored at a memory each micro-second in parallel and the data process is performed by software after getting all echoes.

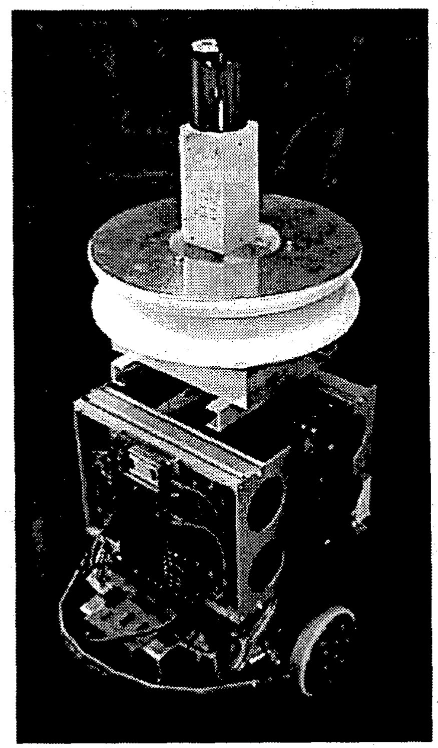

Figure 2: Robot used in this experiment. The robot mount an omni-directional vision on the top, and the omni-directional sonar at hight 50cm from the ground.

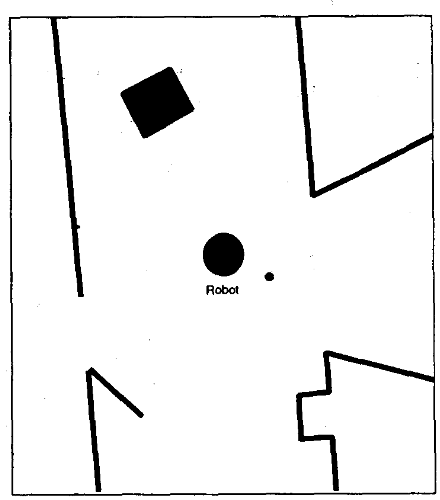

Figure 3: Scheme of experimental environment.

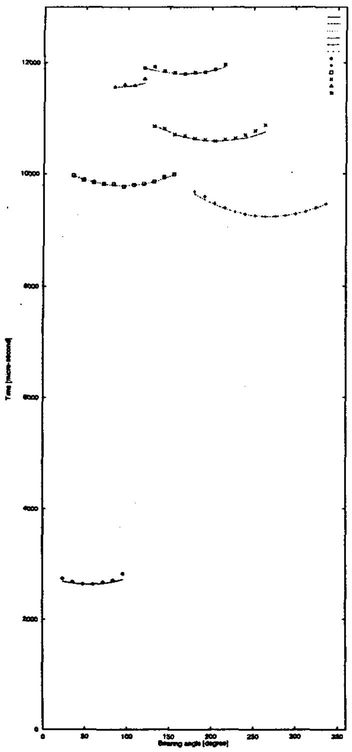

Figure 4: Detected leading edges and fitted quadratic functions. The horizontal axis shows angle of receivers and the vertical axis shows time-of-flights. Minimum peak of the quadratic functions shows distance and direction of the reflecting point.

The processing algorithm calculating accurate direction from time-of-flight difference is as follows:

1. Find leading edges in the signals received by each receiver. (detected leading edges are shown in Fig.4).
2. Correspond the detected leading edges to the object (Grouping).
3. Calculate direction and distance by fitting the data to a quadratic function [5]. (fitted quadratic functions are shown in Fig.4).

As a result, it is possible to measure all the 360 degrees directions in a single transmit/receive cycle, and consequently possible to achieve fast measurement. Resultant detected reflecting points in the experiment are shown in Fig.5.

3.3 Vision process

In the vision, it takes an image using the omni-directional mirror and then process the image to ex-

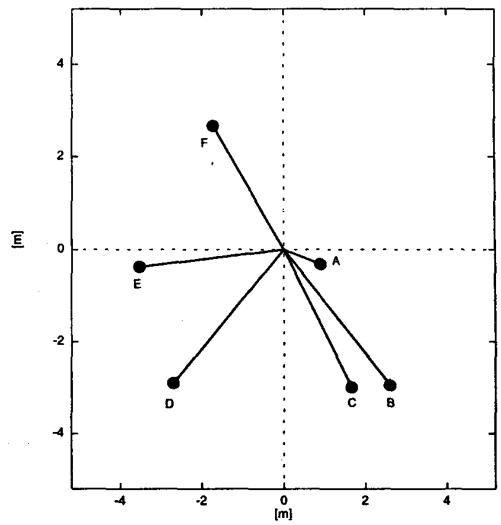

Figure 5: Experimental result in the sonar. The robot is at the origin of the coordinate axes and measured reflecting points are shown.

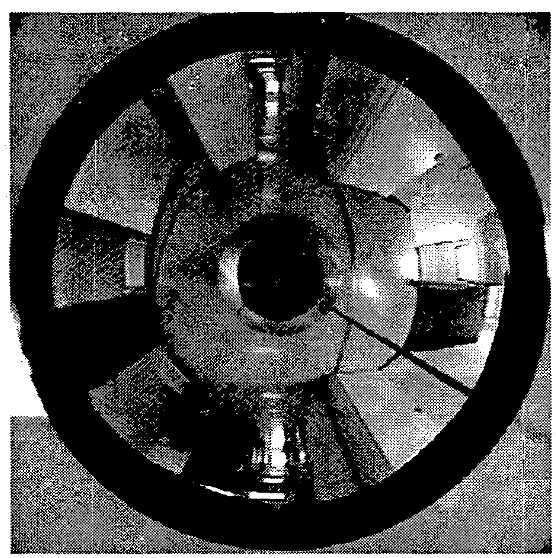

Figure 6: Omni-directional vision image.

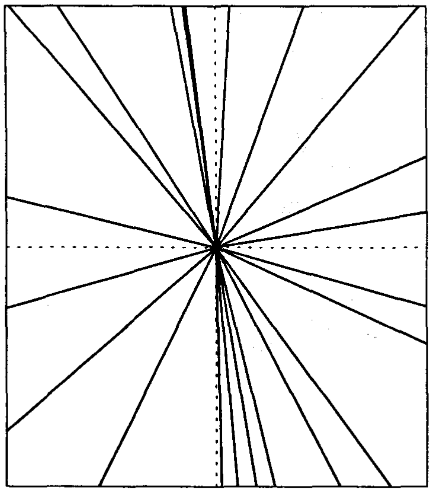

Figure 7: Experimental result in the vision. The robot is at the origin of the coordinate axes, and direction to detected edges are shown.

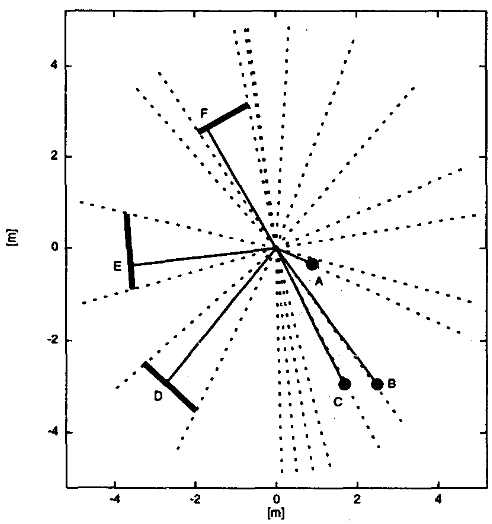

Figure 8: Fused experimental result. The robot is at the origin of the coordinate axes, and detected edges or corners are shown as points, and planes detected by this fusion method are shown in lines.

tract vertical edges. The camera has ability to use in color, but a black and white image was used in this experiment. The image was captured at resolution of 512 × 480 pixels.

The processing algorithm to extract direction of vertical edges is as follows:

1. Spread the round omni-directional image (Fig.6) into the wide image (Fig.9).
2. Extract a part of the image which correspond to hight of the sonar-ring at the distance about 3m around the robot.
3. Differentiate the extracted part, and then extract edges using a threshold level.

In this process, it is possible to know the directions to edges of wall segment. Resultant directions to detected edges in the experiment are shown in Fig.7.

3.4 Fusion

At the part of fusion, the detected edges in vision and the detected reflecting points in sonar are fused based on the bearing angle.

The fusion algorithm is as follows:

1. When an edge in vision exists between ±1 degree in the bearing angle of a reflecting point in sonar, the reflecting point considered as the reflection from an edge of wall segment. And it is remained as a point.
2. When there are no edges in vision between ±1 degree from the detected reflecting point in sonar, the point is considered as the reflection from a plane surface. And then, the nearest two edges in vision are selected in left and right side respectively, and a line denoting a plane surface is drawn by the method mentioned in the section 2.3.

Resultant fused data in the experiment are shown in Fig.8.

4 Discussion

The proposed method could effectively fuse the omni-directional sonar data and the omni-directional vision data. As the result of fusion, the reflecting points on the doors (points D and E in Fig. 5) or the box (F) were recognized as points on the planes, and the reflecting points on the corner, the edge and the pole (A,B,C) were recognized as independent points. This result confirmed that the proposed method is possible to get better information of the environmental feature in the real environment with the single measurement.

Both of an edge detection in vision and an reflecting point detection in sonar have possibility of failure; caused by an occlusion problem and effect of lighting in vision, and by an occlusion problem [5] and difference of power depending on a shape of the reflecting

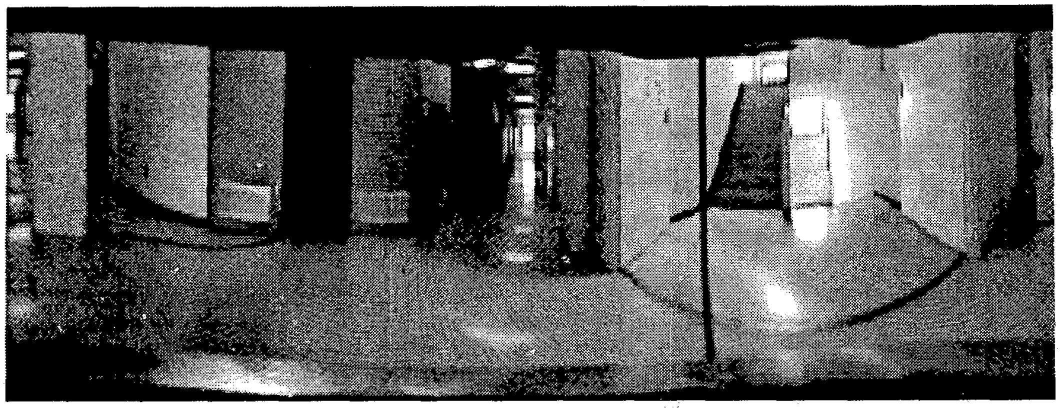

Figure 9: Spread omni-directional image.

object in sonar. Errors at each process cause errors in the fusing process, and also there are possibility of mismatching because only threshold value is used for matching between the two sensors. Accordingly an improvement of reliability and investigation on uncertainty of each sensor are considered as a future work.

In this proposed method is based on the assumption which the indoor environment are structured by plane surfaces. So, if curved surfaces are included in the environment, other hypothesizes are required.

One of the most effective way to over come those deficiency is to use the motion of the robot. Accumulation of the data according to the motion helps to detect and recover the errors.

With respect to the potential of application, concurrent mapping and localization with a robot motion can be an idea, because this sensor fusion method has wider view and gives the distance information which are necessary for safe navigation and localization, and the wall segment information which are useful for mapping.

5 Conclusion

This paper proposes the new method of sensor fusion of the omni-directional ultrasonic sensor and the omni-directional vision sensor for the indoor mobile robot. The new omni-directional sonar, which we developed, can measure accurate distance and direction of reflecting points, and the omni-directional vision can give direction to edges of wall segment. We propose the sensor fusion method using both the reflecting points measured by the sonar and the edges of wall segment measured by the vision, based on the angles. Those data are different in characteristic, so they compensate each other in the proposed method, and it became possible to get better informations which are useful for the environment recognition. Consequently, more accurate and denser information can be got in a single measurement process. The experiment in the real environment was conducted to show the potential and it has high potential on various mobile robots' applications.

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