Vision-Based Navigation of Mobile Robot using Fluorescent Tubes

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Abstract—This paper describes a vision-based navigation method in an indoor environment for an autonomous mobile robot. In this method, the self-localization of the robot is done by detecting the position and orientation of fluorescent tubes which are located above it's desired path thanks to a camera pointing to the ceiling. After explaining how the robot can detect the lights and how the detected landmarks are used to enable the robot's position correction, we will give a brief overview of the mobile robot on which the system has been implemented, and we will report on experiments in a hallway.

Key Words: Navigation, Position identification, Robot Vision, Mobile Robot

1. Introduction

When a mobile robot navigates on a two dimensional plane, it uses sensors to know its relative localization by summing elementary displacements provided by incremental encoders mounted on its wheels. The main default of odometry is that its estimation error tends to increase unboundedly. For long distance navigation, dead reckoning may be supported by an absolute localization technique providing information with a low frequency. Absolute localization in indoor navigation using landmarks located on the ground or on the walls is not easy since different objects can obstruct them. Therefore navigation based on ceiling landmark recognition can be thought as an alternative to this issue. A navigation system recognizing the outlets of air conditioning system located on the ceiling has already been developed for a robot working in construction sites [1]. In this paper, we present how fluorescent tubes can be used as natural landmarks to improve long-term location estimation. We equipped a mobile robot with a camera pointing to the ceiling, so that when a light is detected, it calculates the position and the orientation of this landmark in its own reference and thanks to a map of the lights provided in advance, it can estimate its absolute localization.

2. Fluorescent tube detection

2·1 Fluorescent tube model

It is natural to think of fluorescent tube as a natural landmark for a vision-based process aimed at improving the location of a mobile robot in an indoor environment. Indeed, problems such as dirt, shadows, light reflection on the ground, or obstruction of the landmarks usually do not appear in this case. One advantage of fluorescent tubes compared to other possible landmarks located on the ceiling is that once they are switched on, their recognition in an image can be performed with a very simple image processing algorithm since they are the only bright elements that are permanently found in such a place.

If a 256 grey levels image containing a fluorescent tube is binarized with an appropriate threshold $0 \leq T \leq 255$, the only element that remains after this operation is a rectangular shape. If we suppose that the distance between the camera and the ceiling remains constant and that no more than one light at a time can be seen by the camera located on the top of the robot, a fluorescent tube can be modeled by a given area S_0 in a binarized image of the ceiling.

2·2 Fluorescent light detection process

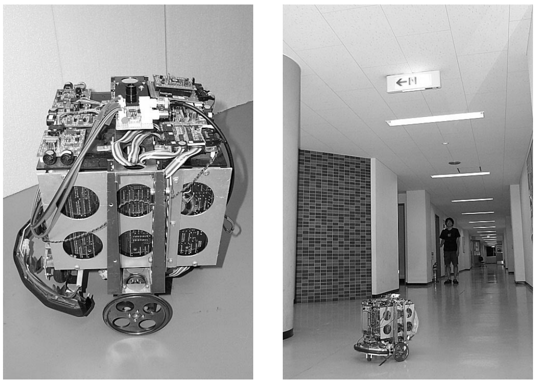
The robot is given in advance a map of the lights. The first information contained in the map for each light is its location in a global referential. Using odometry, the robot is able to know when it gets close to a light by comparing in a close loop its actual estimated position to the different locations of the lights. Once it gets close to one of them, it starts taking images of the ceiling and binarizing the images with a default threshold $0 \leq T \leq 255$ until the number N of pixels brighter than T becomes greater than S_0. When it happens to be true, the detection algorithm is stopped and further image processing is done.

In order to discard too bright images, the detection algorithm increases automatically the threshold if $N \geq S_1$, where S_1 is a given value greater than S_0. T, S_0 and S_1 depend on each light and are stored in the map. Moreover, because the intensity of the light emitted by fluorescent tubes changes with a frequency of 50Hz, the threshold has to be decreased automatically if $N \leq S_0$, so that the robot has a chance to detect the light located above it even if this one appears darker than usual. Besides, upper and lower limits are set so that T belongs to an appropriate interval for light detection.

3. Estimation of the absolute position

The detection algorithm has been designed so that the position of the fluorescent tube is calculated only if the whole shape of the tube appears in the captured image. Therefore it is possible to calculate the location of the tube's centroid in the image as well as the orientation of its least moment of inertia axis using the moment-based features of the binarized shape. By converting the previous values into the robot's local reference and using the exact position and orientation of the light provided by the map, it is possible to determine the absolute localization of the robot.

Once the absolute localization is obtained, it can be fused with the estimation of the robot's relative position so that it can correct its trajectory. In the case of non rectangular fluorescent lights, the orientation of the binarized shape is ignored. Note that the method we chose to



a b

Fig.1 The YAMABICO robot with the top board camera and the target environment.

calculate the location of the light in the image is based on statistic properties Therefore, the noise existing in the binarized image can be ignored if it remains small, that is to say, if the threshold used for binarization is suitable.

4. Implementation and experiment

We implemented this system on the YAMABICO robot developed in our laboratory as shown in Figure 1.a. The sensors used by the robot to estimate its localization are optical encoders mounted on the wheels and a board CCD black and white camera facing the ceiling. The navigation program and the absolute position estimation program based on fluorescent lights are completely independent. It is therefore possible to run simultaneously other localization estimation programs based on different landmarks without any modifications.

Since the calculation of the robot's absolute position estimation from an image is time consuming, retroactive data fusion with odometry data is necessary. This function is achieved thanks to a special module on the robot using the extended Kalman filtering [2].

In order to prove the reliability of absolute localization based on the detection of fluorescent lights, we compared the localization estimated by the robot to its real localization by setting its position on different places under a fluorescent light. On each position, several measurements where made for three orientations of the robot with respect to the light: 0, 45 and 90^o. The average error on the position estimation is less than 5cm and less than 2 degrees for the orientation if the robot remains in a disc of 120 cm diameter centered on the centroid of the light. Figure 2 shows the estimated position of the robot in one quarter of the disc defined previously. Because of the camera's distortion, the errors on both position and orientation estimation grow as the robot leaves the disc, which makes absolute localization difficult when a landmark detected by the robot is not close to its vertical. Further image processing will be done to correct the distortion in future work.

The validity of the proposed navigation system has been shown by making experiments in a corridor at different times of the day. The robot had to navigate in the middle of the corridor until a defined point and then had to go back to its starting point several times. The target environment is shown in Figure 1.b. The maximum speed of the robot was 37 cm/s and total distance on one way was about 37 meters. On the robot's path 12 fluorescent tubes

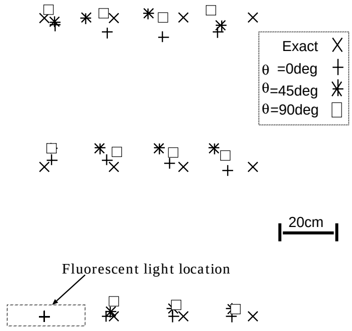


Fig.2 Position estimation results for several positions and orientations of the robot.

of different shapes where present, separated by a distance varying from 2.2 meters to 3.8 meters. The experimental results of one of those tests are shown in Figure 3 where the rectangles and squares represent the fluorescent lights and the curved line corresponds to the odometry data of the robot. When a light is found, the absolute localization of the robot is corrected after a certain delay, which leads to the peaks on the robot's trajectory in Figure 3. During this experiment, the robot missed the fourth light and did not correct its absolute localization using the vision system at that time. More generally, the robot could cope with lights switched off and changing in the lightening conditions of the corridor and it could adapt automatically the threshold to detect the lights.

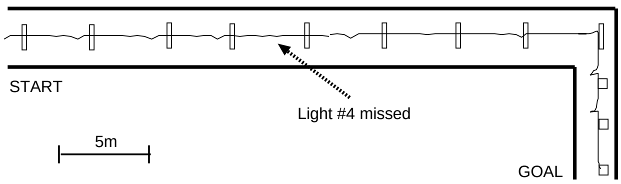


Fig.3 Correction of the robot trajectory using the detection of fluorescent lights in a coridor.

5. Conclusion and future work

In order to improve the localization of a mobile robot using odometry as a default dead-reckoning system, we proposed in this paper a method using fluorescent tubes so that the mobile robot can know its absolute position while navigating in an indoor environment. Further work will involve correcting the image distortion to make possible the use of fluorescent lights even if the robot does not have to navigate exactly under them.

References

1) T. Fukuda, et.al., "Navigation System based on Ceiling Landmark Recognition for Autonomous Mobile Robot", Proc. of 1993 International Conference on Industrial Electronics, Control, and Instrumentation, Vol.3, pp 1466-1471.

2) S. Maeyama, A.Ohya, S.Yuta "Non-stop outdoor navigation of a mobile robot - Retroactive positioning data fusion with a time consuming sensor system", Proc. of 1995 Intelligent Robots and Systems, Vol.1, pp 130-135.