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Use of the Parallel and Perpendicular Characteristics of Building Shape for Indoor Map Making and Positioning

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Abstract— **We are trying to develop an easy autonomous map making method for indoor mobile robots, using the property of the usual buildings, which we can assume that the major walls are arranged parallel or perpendicular. Based on these properties, the robot can find its own direction easily, with its surroundings range data, so that the accumulated error in the calculated direction can be avoided. In this paper, we propose a method to know the robot direction using scanned range data of the environment walls, and the method to build the map by connecting the scanned range data using this property. We also present an example of experimental results of indoor map making by a mobile robot without using the odometry, which shows the effectiveness of the proposed method.**

I. INTRODUCTION

For the autonomous mobile robot which performs various tasks by itself, the precise positioning of its location is a very important function. The robot estimates its position with an environment map like the way humans do. For developing an environmental map, it is indispensable to define its precise present position. Consequently, the position estimation and the map making should refer to each other. To solve this problem, Simultaneous Localization and Mapping (SLAM) , which enables simultaneous definition of the present location and the environmental map, has been widely studied[1]-[3]. One of the major techniques for SLAM is the Localization and Mapping Method, with using scan matching methods[4]-[11].

The scan matching method, which uses the sets of two dimensional position data measured with laser scan sensors, are widely used for producing an environment map by mobile robots. The scan matching method is a technique, which estimates the displacement of the posture of the robot (both translational and rotational position) based on the difference between the scan data obtained before a movement (a reference scan) and those of the present position (a current scan).

A lot of efforts have been made to develop an efficient technique for the scan matching. However, the each scan matching process produces some errors on the calculated displacement. And as long as the map is created based on the successive matching processes, these errors are accumulated and affect the accuracy of the resulting map. Especially, cumulative errors on direction angles would seriously deteriorate the consistency in the map, and make the map unsuitable for practical use.

Usually, people can perceive an environment model very easily in the building when it is mainly constructed with parallel and perpendicular walls. So we expected that we could have a simpler scan matching method for inside of such an arranged structure like the interior of a building, by considering on the mechanism how a human knows the direction inside of a building. Inside of a building, a human knows the direction without the accumulation of motion information. He/she knows that the corridors are principally positioned parallel or perpendicular to each other, and based on this assumption he/she can tell the direction from relative arrangement of the nearby wall and the wall at the starting point. The human unconsciously estimate his/her position using the wall at the entrance as a reference, and since this estimation is made referencing the fixed structure of a building, it is not accompanied by any cumulative errors.

In this work, we developed a direction angle detection algorithm using these characteristics of a building environment. After knowing the direction angle of the robot, the scan matching to know the displacement between positions of reference scan and current scan, can be easily done by only the estimation of translational shift. So that we have realized a stable quick map creating method for a use in a large building.

In this report, we propose a method for estimation of a robot direction in a building and translational displacement, using the laser scan sensor data. In the direction estimation, the histograms of the projected scan data for all directions are used to find the direction of the major walls. And the translational displacements are estimated using the correlation of histograms of projected scan data, only in parallel or perpendicular direction. The proposed methods are tested in creating a map under practical conditions to show the effectiveness of the method.

Fig. 1. Scenery of inside of the building (University of Tsukuba, Hall L)

II. ROBOT HEADING ANGLE ESTIMATION

In this study, it is assumed that the robot is working in a building, whose interior is dominantly composed of flat walls and walls are positioned parallel or perpendicular to each other. The indoor environments such as many offices suit this condition. The robot scans it's around two-dimensionally to obtain information of the shape of environment using the scanning laser range sensor, and based on the geometrical characteristics of indoor environment structure, it estimates its direction.

A. Measurement of relative angle between the robot and major wall

In the proposed method, the angle of the wall around the sensor is calculated by statistical handling of the scan data without distinguishing explicitly which part of the scan data indicates the wall. In this process, the longest straight line in the scan data is regarded as the major wall and the angle between the heading direction of the robot and the wall is obtained.

The data processing procedure after obtaining two dimensional position (x, y) data sets is shown below. Since our practical robot is equipped with a scanning laser range sensor UTM-30LX (Hokuyou Automatic Co.), in which the range data in the view-angle of $\pm 120°$ are collected, the algorithm and parameters are given under the assumption of using this type of sensor.

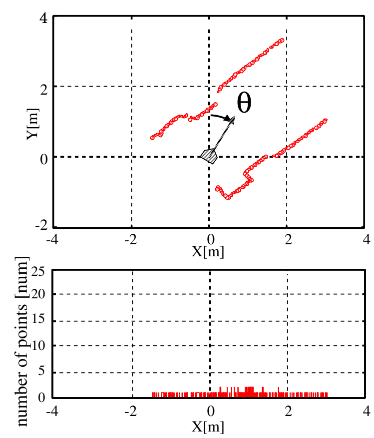
1) The positions of reflecting points in the scan data are obtained in the two dimensional robot coordinate, where on the sensor position is the origin. The reflected point data are thinned down to have roughly constant interval. (Practically, the intervals are set as roughly 0.05 m.)
2) The reflecting points in the scan data are rotated with small angle in θ direction around the robot. (Step size of the rotation is set as $0.1°$.)
3) In each rotating direction, reflecting points are projected to the X-axis of robot coordinate, and the histogram along the X-axis is made. (The bin size for the histogram is 0.020m along the X-axis.)
4) The maximum value of the histogram is recorded as $h_{max}(\theta)$, for each rotation angle θ.
5) The rotation angle θ, which gives the largest $h_{max}(\theta)$, is regarded as the angle of the major wall relative to the robot direction in this scan data.

Fig.2 and Fig.3 depict this procedure using the experimental scan data. The scan data was obtained in a building, on the third floor of the department of engineering, University of Tsukuba, shown in Fig.1. The spatial data were collected at the height of 0.3m from the floor. The sensor is set at the origin of the robot coordinate, and oriented to the same direction as the robot heading. The data shown here were obtained when the robot was positioned at about $20°$ counterclockwise off the plane of the wall.

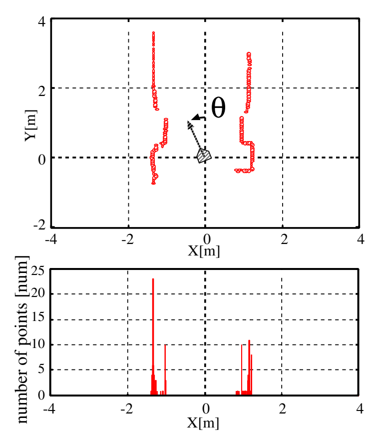
Fig.2 shows the scan data rotated with the direction of θ, and the results of projection to X-axis of them. Fig.2(a) shows the result in the case that the direction of the data rotation, was greatly deviated from the direction of the wall. The profile of the bottom of the histogram was rather flat to the location. In the case of Fig.2(b), the direction of the projection is parallel to the wall, and the histogram shows fine profiles at distant positions.

Fig.3 shows the largest voted numbers of the X-axis projection at each rotation angle θ. The θ which gives the maximum votes in this figure is regarded as the angle between the robot and the wall.

The principle of this method is almost same with the straight line detection algorithm using the Hough transform[12]. Differences between the methods in this work and in the straight line detection using the general Hough transform is found in the setting and calculation order of the bin for obtaining the histogram in the parameter space. This method utilizes the information of point groups without reproducing images out of the scan data, and makes highly accurate estimation of the angle. In addition, the calculation does not require a large memory, because it deals with only the largest voting numbers for each angle.



(a)Case of off-parallel angle to the wall



(b)Case of parallel angle to the wall

Fig. 2. Rotation of sensor data and its projection

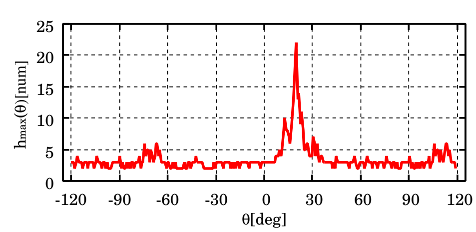


Fig. 3. Maximum value of votes for each θ

B. Estimation of the absolute direction of the robot

The procedure in the previous section gives a relative direction of the robot to the major surrounding wall at the current position, using one set of scan data. Here, the absolute direction of the robot is estimated, taking into account the fact that the walls in a building are installed parallel or perpendicular to one another.

At first, the major straight line of the wall detected at the initialized position is defined as a standard direction. At each current position, the detected major wall can be assumed to be parallel or perpendicular to the standard direction. And, the parallel or the perpendicular is decided based on the assumption that the robot direction dose not changes so rapidly. So, after the robot detects the relative direction to the current major wall and if the relative direction changes more than $\pm 45°$, it is interpreted that the current major wall is shifted to the next wall which is perpendicular to the previous one. So, by continuous detection of the relative direction of the robot to the major wall, the absolute direction to the standard direction of the environment can be tracked.

III. Estimation of Translation

Usually, the environmental shape in the buildings has special features in two directions, ie. the standard (y-axis) direction and its perpendicular (x-axis) direction. These directions relative to the robot are detected in section II. Here, we propose to use the projections (or the histograms) of the scan data on x and y coordinate axis and their correlations, to know the translational displacement between the robot positions of getting reference and current scans.

The use of the one dimensional projection (or histogram) instead of two dimensional point sets and their correlation in scan matching has been already proposed [6]-[8]. However, in these researches, the parallel and perpendicular characteristics of the environment shape were not explicitly used. In our method, we propose to use the particular parallel and perpendicular directions of the major walls. And this idea is very effective to calculate the translational shift from scan data with reduced computing time.

A. Histogram on major direction axes

First, the histogram on x and y axis are made from each scan data by projection to two axial direction. Here, let's denote these histograms by $h_x(i)$ and $h_y(j)$, where, $h_x(i)$ shows the number of projected points in the i-th bin on x-axis and $h_y(j)$ shows that in the j-th bin on y-axis.

Fig. 4 shows an example of histograms made by projection to the two axes for the practical experimental data, in which the size of bin is set as 0.030m. The raw scan data are experimentally obtained under the same setting as in the section II. The origin of the graph is the position of the sensor. The Y axis is allocated to the direction of the longest straight line explained in section II. The obtained histograms for the two directions possess fine structure in their profiles, indicating that the original data has a high two dimensional resolution.

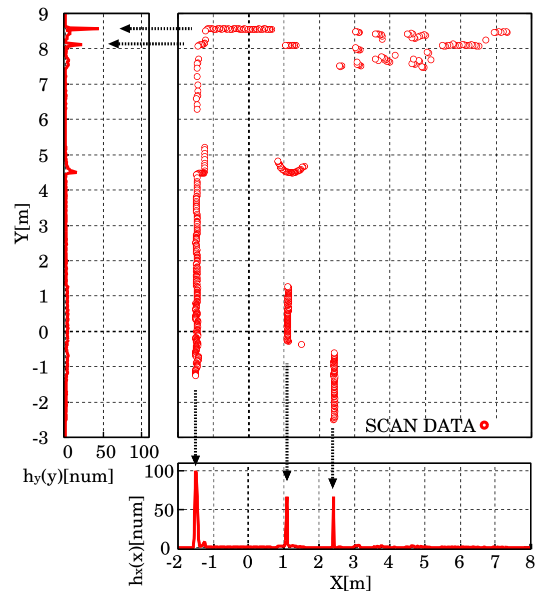


Fig. 4. Experimental Scan data and their projections for the parallel/perpendicular directions of major wall

B. Matching by correlation of histograms

In this method, matching of two sets of scan data is conducted by comparison of histograms obtained along the two major axes. The correlation of the histograms between the reference scan and the current scan histogram is obtained as follows:

$$E(k) = \sum_{i=1}^{n} h_{ref}(i) h_{cur}(i+k)$$

where h_{ref} and h_{ref} represent the reference scan and the current scan, respectively.

The resolution of the scan matching in this method depends on the size of the bin to make histogram. When the size of the bin is set too small, the measurement errors of reflection points and the limitted number of the reflection points make an serious influence on the result. Therefore, in this work, the displacement interval of each scan was set at a smaller distance than the size of bin. When defining the histogram which was obtained after displacement of (x', y') as $h_{x\ cur}(i, x')$ and $h_{y\ cur}(j, y')$, the correlations between h_{ref} and h_{cur} are given as follows:

$$E_x(x') = \sum_{i=1}^{n} h_{x\ ref}(i) h_{x\ cur}(i, x') \quad (1)$$

$$E_y(y') = \sum_{j=1}^{n} h_{y\ ref}(j) h_{y\ cur}(j, y') \quad (2)$$

Then, we can get the relative translation between reference and current scan as follows:

$$trans_x = \arg\max_{x'} E_x(x')$$
$$trans_y = \arg\max_{y'} E_y(y')$$

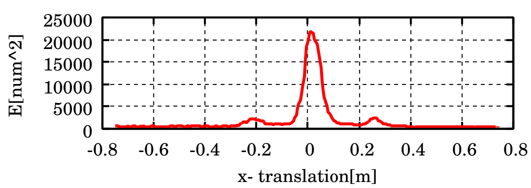
In this method, the computation time is not large, because the calculation can be independently done only for x and y axis, and finding the maximum value of the correlation is simple one dimensional search problem. So, the search can be made in whole area without the iteration, and it is not necessary to select the good initial value for the optimization in the practical computation time.

Fig.5,6,and 7 show the data processing procedure using an example of experimental scan data. As Fig.4, the scan data are measured on the third floor of the department of engineering, University of Tsukuba. The data collection was conducted at the height of 0.3m above the floor. After taking the reference scan data, the robot moved about 0.3m in the Y direction and 0m in the X direction, then the current scan data were obtained.

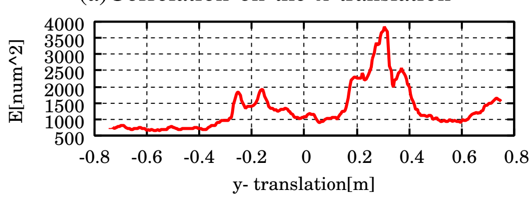
In Fig.6, reference data and the current scan data was shown in two dimensional plane. The direction of the axes is determined by the method mentioned in the section II. Then the correlation of histograms is examined for the current scan data, shifting them by 0.005m pitch in the range of ± 0.800m in the two directions where, the size of bin is 0.030 m.

Fig.5(a) and 5(b) show the correlation $E_x(x')$ and $E_y(y')$ values corresponding to the shift of the current scan along the axes.

There is a peak at +0.015m in Fig.5(a). In Fig.5(b), there is a peak at + 0.305 m. Fig.7 shows the result adopting the values of shift estimated from Fig.5. The two sets of scan data have made a complete match in Fig.7.



(a)Correlation on the x translation



(b)Correlation on the y translation

Fig. 5. Experimental result of correlations for x- and y- translation

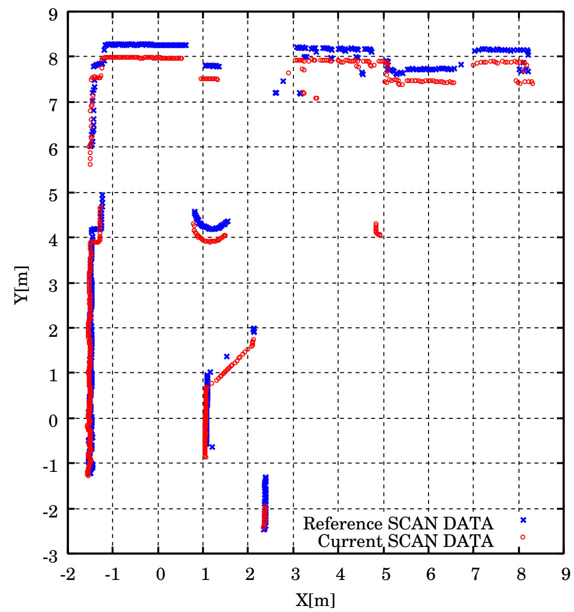


Fig. 6. Two scans adjusted with each longest wall

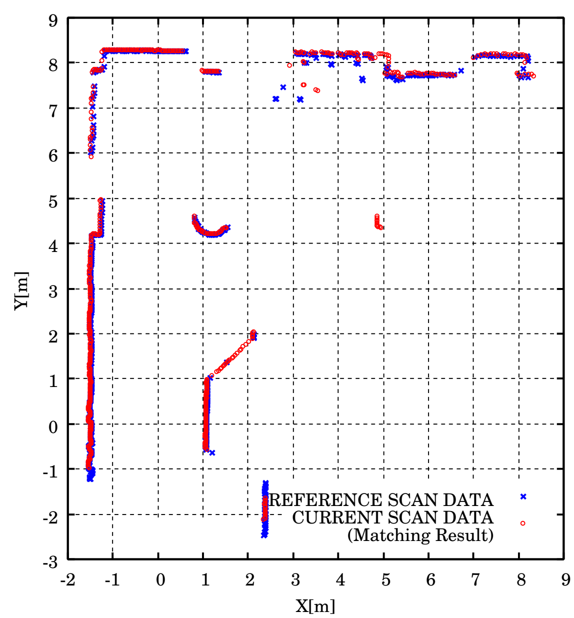


Fig. 7. Result of scan matching

IV. Map Building Experiment of a Large Area

A. Environment

The experiments were conducted in a course of the corridors of a large building of the department of engineering, University of Tsukuba, which has the size of 190m by 50 m. In this building, the long parallel walls are connected at right angles. The robot equipped with a sensor (UTM-30LX, Hokuyou Automatic Co.) was used for the measurement, and the horizontal plane at the height of 0.3m from the floor was scanned. In the experiment, the robot was controlled manually by an operator using a remote joy stick. The measurement was automatically carried out when the robot made a translation about 0.3m or rotated 10° by robot controller.

B. Results and discussion

Fig.8 and Fig.10 are the resultant maps generated in this experiment, in which the measured scan data were joined together with obtained direction and translational shift by the methods given in section II and III. In this experiment, the operator manually controlled the robot show by arrows in Fig.9, where, the start point was set at the north end of the building L. The robot followed the path from building L to G in the order of L, M, F, E, C, D, G. Total travel distance was 430m (including a loop for about 320 m), and the number of scans was 1054 times, and the robot and operator took about 12 minutes to move the experimental path. It took about 0.03 second for each scan matching, using a small size note-book computer (OS:Linux, CPU:Core2Duo 2.5GHz, RAM:3.2GB DDR2).

As shown in Fig.8, each scan data were properly processed with the matching method, and the structure of the corridor was reproduced successfully. Fig.10 shows a magnification of the crossing point of the path, at the location in side of the building G where the loop is made. There was only a small deviation of 0.24m in the X direction and 0.22m in Y direction. Compared with the travel distance 320m during the loop, these deviations were very small. This result shows that the proposed method has no cumulative errors in angles and also small errors in the translational matching. It is found that the proposed method, which connected the scanned data, could produce a sufficiently correct map during the long distance travel. The result was obtained without using odometry information for estimation even for the initial value of each matching process. No error in matching was observed in this environment, which suggests high reliability of our method. Also, from the point of view in calculation time, the proposed method is efficient for producing environmental maps inside of buildings.

V. Summary

In this work, we developed a new method for generating the environmental maps of inside the buildings, where walls are arranged in a straight shape and parallel or perpendicular positions. The direction of the present location is determined by environmental measurements, and the translational movement is estimated by the simple scan data matching. The experiment with a robot proved the efficiency of this method, when it is carried out inside of a building.

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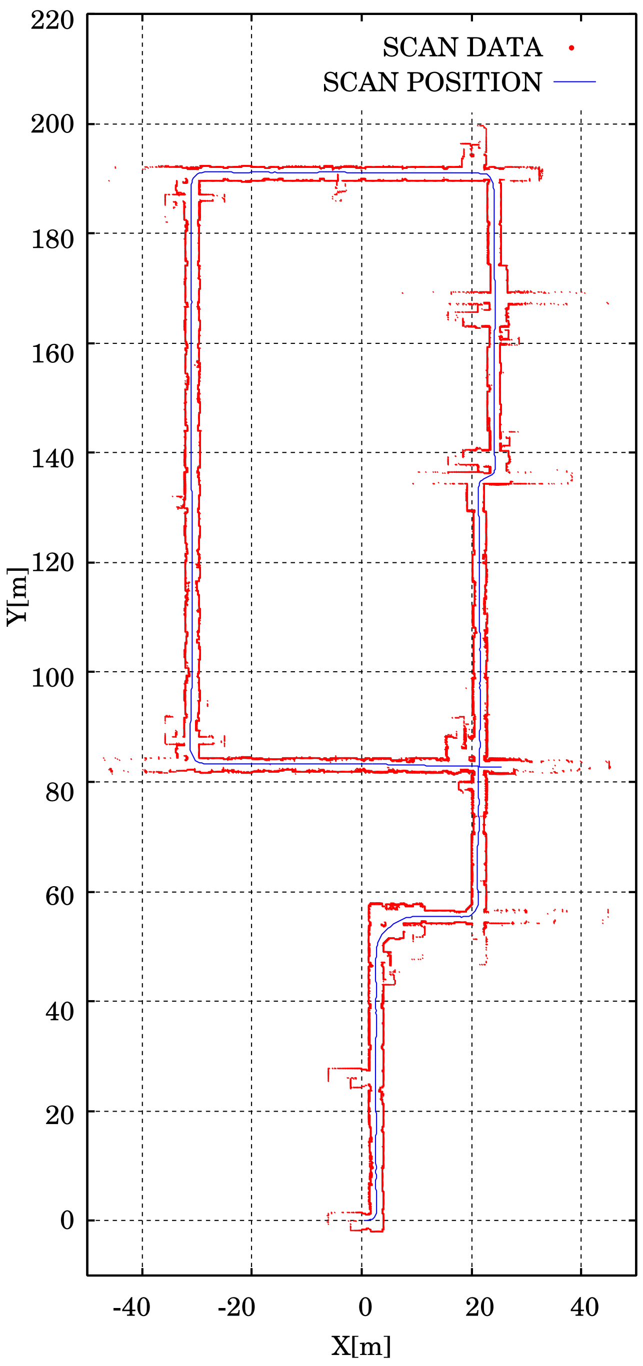

Fig. 8. Experimental result of the constructed map using the proposed method

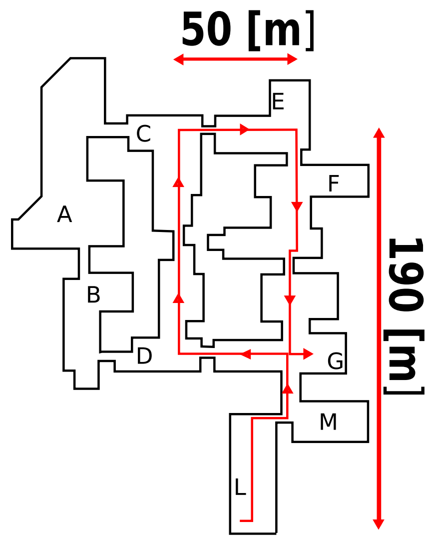

Fig. 9. Track of experiment - Enginieering department Buildings in University of Tsukuba

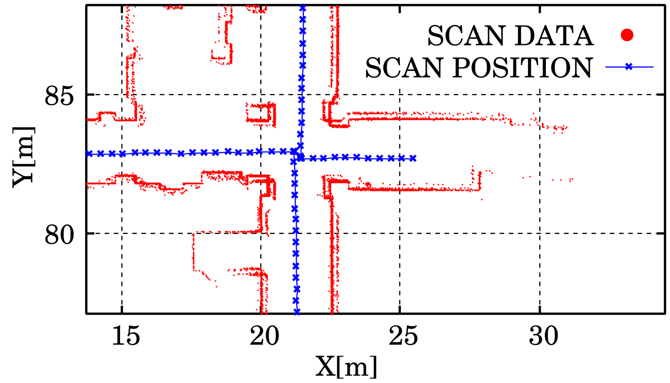

Fig. 10. Intersection between the out- and homeward paths