Memory-Based Navigation using Data Sequence of Laser Range Finder

Yoshihisa Adachi, Hiroaki Saito, Yoshio Matsumoto, Tsukasa Ogasawara
Graduate School of Information Science
Nara Institute of Science and Technology
http://robotics.aist-nara.ac.jp/

Abstract

In this paper, we propose a novel navigation method for a mobile robot using a laser range finder based on the memory-based approach. A robot memorizes sequential scanning data of the laser range finder in the recording run. Then the localization of the robot is achieved based on the matching between the current scan and memorized scan sequence in the autonomous run. The matching process utilizes histogram-based method proposed by Weiss et al. Experimental results of the recording run and the autonomous navigation is presented to show the feasibility of the proposed method.

1 Introduction

In the field of artificial intelligence, "Memory-Based Reasoning"[1] has been studied for a long time. The aim is to solve complicated problem in real world by using enormous memories and simple matching techniques. The application of this approach for pattern recognition is called "View-Based Approach" or "Appearance-Based Approach." Owing to the recent drastic improvement of the computer technology, this approach has become feasible in many application areas.

In vision-based mobile robotics, there has been some researches based on the view-based approach. It is necessary for a robot to have a teaching stage in order to memorize the appearances in the environment. Since the data size of the appearance is large in general, keys to the success in this approach are (1) how to memorize the appearances and (2) how to achieve the matching between appearances. Matsumoto et al. have proposed a view-based navigation method using a model of the route called the "View Sequence"[2],[3]. This model contains a sequence of view images which are memorized successively along a route in the recording run. In the autonomous run, by comparing the current view image with the memorized view sequence, the robot detects its position and takes the appropriate action to reach the goal. However, it was not possible to estimate the accurate position using this method, since it utilizes only two dimensional view of the environment. Moreover, the matching process is not robust against the changes in illumination.

A laser range finder is a sensor with high accuracy in the distance. There has been some researches using the laser range finder for localization of the mobile robots [4] [5]. These methods need an a priori map of the environment and estimate the localization by matching between the current scan and the map. However preparing such accurate map is not easy.

In this paper, we propose a novel navigation method for a mobile robot using a laser range finder based on the memory-based approach. A robot memorizes sequential scanning data, called "A Scan Sequence" based on the idea of View Sequence in the recording run. Then the localization of the robot is achieved by the matching between the current scan and memorized scan sequence in the autonomous run without a prepared map. Experimental results of the recording run and the autonomous navigation is presented to show the feasibility of the proposed method.

2 Navigation Method using Scan Sequence

2.1 Outline

In the navigation method using a scan sequence, there are two stages to the run. One is termed "recording run", and the other "autonomous run".

Recording Run

"A Scan Sequence" consists of a sequence of scanning data along a route which are taken at a certain interval. The robot first performs a recording run under manual operation and memorizes the sequence of scans automatically. The position where the scan is memorized on the route is called a "node" and its scan is called a "node scan". A node scan consists of frontal scanning data of 180 degrees. The node scan is memorized with the action of robot from the previous scan such as "go forward", "turn to the right." **Figure** 1 shows the outline of the recording run.

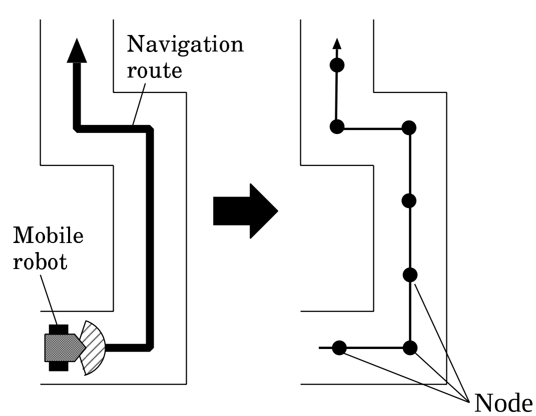


Figure 1: Recording Run

Autonomous Run

When a robot makes an autonomous run to the destination, it refers a node scan in the memorized sequence in accordance with its position. At the starting position, the robot takes matching between the current scan and the first reference node scan in the scan sequence. Then during the autonomous run, the relative position dx, dy and orientation $d\theta$ are calculated by the matching process between the current scan and the reference.

The action of the robot such as "Going Forward" and "Turning Right" is determined by the action information which was memorized together with the scan node. The value $\Delta\phi$, which is given as follows:

$$\Delta\phi = d\theta - \tan(\frac{dy}{dx}). \tag{1}$$

is utilized for motion control. In the case that the memorized action of the robot is "Going Forward," it moves forward directing to the position of the reference node whose scan matches with the current scan. When the robot reaches the position of the current reference node scan, it switches the reference node scan to the next one in the scan sequence. In the case that the action of the robot is "Turning," the robot switches the reference node scan to the next one when the relative orientation between the current scan and the reference node scan becomes sufficiently small. By repeating the action described above, the robot can reach the destination.

2.2 Matching Method

The matching process utilizes a histogram-based method which is an extension of the matching method proposed by Weiss et al [6]. The outline of the process is described as follows:

1. To calculate angle-histograms of two scans and find the angular displacement $d\theta$ between them which gives the highest correlation.
2. To rotate the current scan by $d\theta$.
3. To calculate translation histograms of two scans for x and y directions.
4. To find the highest correlations dx, dy for x and y directions using histograms.

By connecting all consecutive points in a scan, the scan can be represented as a set of short lines. Then the direction of each line is calculated for all points in order to create a histogram which is called an "angle-histogram." If a scan contains a straight line segment in a environment such as a wall, all the angles for the segment should be the same. However, noises in the scan and the quantization error prevents them from being the same. Thus grouping of the points which belongs to a line segment is performed before making a histogram.

For grouping points, the value E which is defined as the following equation is utilized:

$$E = d_{start+n-1} - \frac{d_{start}d_{start+n}\sin n\theta}{d_{start}sin(n-1)\theta + d_{start+n}\sin\theta} \tag{2}$$

As shown in **Figure** 2, E represents the distance from a point to a line segment. If the value E is under a threshold, points from $start$ to $(start+n)$ can be regarded as linear, and the number of points in the line is accumulated in the angle-histogram $h(x)$. Since the line

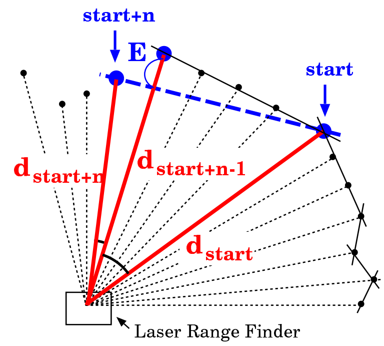


Figure 2: Line segments detection

segments are quite short, small errors in range data produces relatively large errors with regard to the direction. Thus the angle-histogram tends to be noisy, and following average filter is applied to the angle-histograms in order to obtain smooth correlation results.

$$h'(x) = \frac{1}{2k+1}\sum_{i=x-k}^{x+k} h(i) \tag{3}$$

The rotational displacement between the current scan and the node scan can be obtained by calculation of the cross-correlation of two angle-histograms h_1(current scan) and h_2(node scan). **Figure** 3(a) shows an example of two angle-histograms, i.e. a current scan and a node scan. The correlation of them is defined as follows:

$$c(j) = \sum_{i=1}^{N+1} h_1(i)\cdot h_2(i+j) \tag{4}$$

By finding the highest correlation, the rotational displacement between two scans can be obtained. **Figure** 3(b) illustrates the correlation between two angle-histograms shown in **Figure** 3(a).

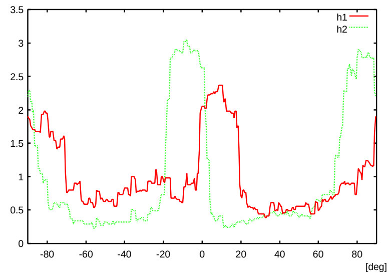
Then one of the angle-histogram is rotated by the obtained rotational displacement $d\theta$. After the orientation of the scans are corrected, the translational displacements in x and y direction, dx, dy are calculated by using x-histogram and y-histogram in the similar manner.

2.3 Expansion of a node scan to 360 degrees

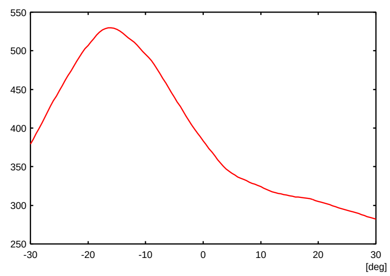
Our robot has the laser range finder which can detect the front data of 180 degrees. Therefore, an autonomous run can be carried out only in the same direction as a recording run. Getting data of 360 degrees at each node, a run for the inverse direction can be attained.

In order to obtain a scan of 360 degrees, the robot performs following procedures:

1. On a node, the robot scans the range data of 180 degrees as a reference data.
2. The robot turns approximately 30 degrees.
3. The current scan is obtained and the relative position dx, dy and orientation $d\theta$ are calculated based on matching between the current scan and the reference data.
4. After being rotated and translated by dx, dy and θ, the current scan is added to the reference data.



(a) two angle-histograms

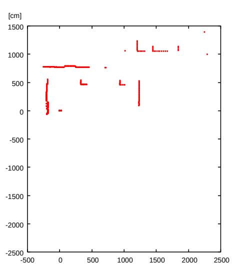


(b) correlations between two angle-histograms

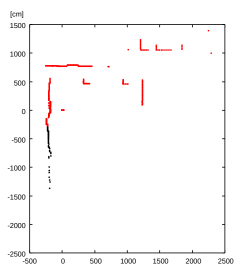
Figure 3: Angle-histograms and the correlations

5. From 2. to 4. are repeated until the data of 360 degrees are acquired.

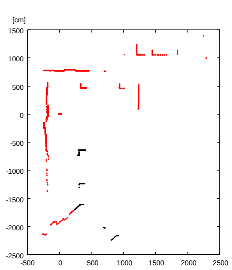
Figure 4 (1)∼(4) shows the result of the scanning process at a node, where (1)only 180 degrees are scanned and (4) range data of 360 degrees are obtained. The robot locates at the position of (0,0). The data of 360 degrees acquired at each node is utilized as the reference node scan in an autonomous run.



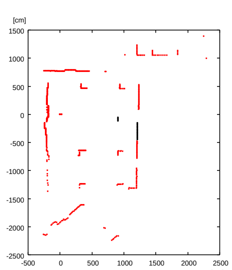
(1)



(2)



(3)



(4)

Figure 4: The acquired data of 360 degrees

3 Experimental Results

3.1 Mobile Robot System

Figure 5 and **Figure** 6 show the overview and system configuration of the experimental mobile robot system. The appearance of the robot system is the character of Ikoma City named "Takemaru." We adapted a commercial electric wheelchair for indoor-use (MISAWA M-Smart) for computer control by installing a PC (Celeron 1GHz) inside our robot. **Table** 1 shows the specification of our system and **Table** 2 shows the specification of the laser range finder in the system.

Figure 5: Robot System Overview

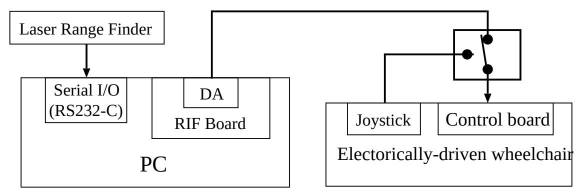


Figure 6: System Configuration

Table 1: The specification of our robot system

Size(Diameter)	130[cm]
Height	130[cm]
Electric wheelchair	M-Smart (MISAWA)
PC	Celeron 1GHz
Laser range finder	LMS 200 (SICK)

Table 2: The specification of laser range finder

The measurement range of distance	Max 80[m]
Resolution of the angle	0.5[deg]
The range of angle	0∼180[deg]
The number of data	361
Response time	26[ms]
Resolution of the measurement	1.0[cm]
System error	±4.0[cm]

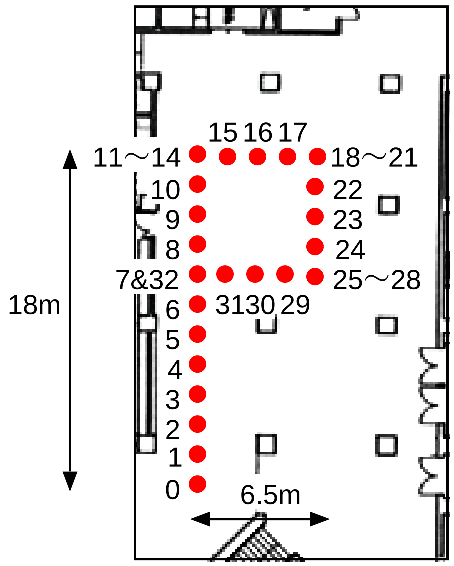


Figure 7: The route of the experiment

3.2 Navigation Experiment

Experiment of Navigation using the node scans of 180 degrees

The experimental result of the autonomous navigation using the node scans of 180 degrees obtained in the recording run is described in this section. The experimental environment is the first floor of Ikoma City North Community Center "ISTA Habataki." **Figure** 7 shows the route of the navigation and the arrangement of nodes. 24 nodes are arranged on the route at approximately 1.6m intervals and nine nodes are arranged on three corners. The node scans are memorized at these nodes in the recording run under manual operation.

Figure 8 shows the sequence of navigation in the autonomous run. The left column indicates images of the mobile robot running autonomously. The right column indicates the current scan and the reference node scan. When the displacement in the anteroposterior direction (i.e. the direction to move) between the current scan and the reference scan becomes zero, the reference scan is changed to the next one in the memorized sequence. **Figure** 9 shows the set of node which was given in the recording run, and the route in the autonomous run. It is shown that the autonomous navigation was performed well.

Figure 10 shows the correlation values between the current scan and the node scan for the orientation θ and the position x and y in this experiment. At nodes No.12∼14, No.19∼21 and No.26∼28, the correlation values of the orientation was low. This is because these nodes locate at the corners, and the changes of scan in the orientation tend to be large. At nodes No.14∼ 18 and 28∼32 the correlations of y-direction was high since long walls exists in the front.

Table.3, the navigation error and localization error are shown. The navigation error is the difference between the recorded node position and the trajectory in the autonomous run. The localization error represents the difference between the actual position and the estimated position based on matching. The navigation experiment was conducted three times and **Table**.4 shows

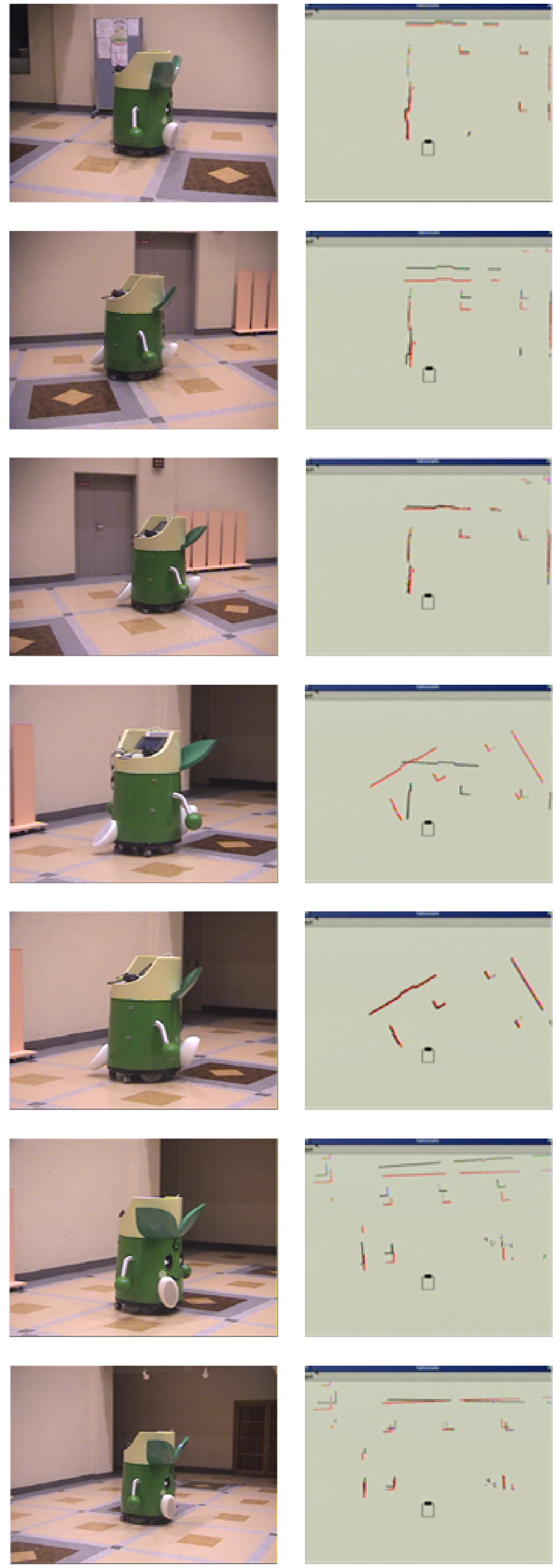


Figure 8: The sequence of navigation in the experiment

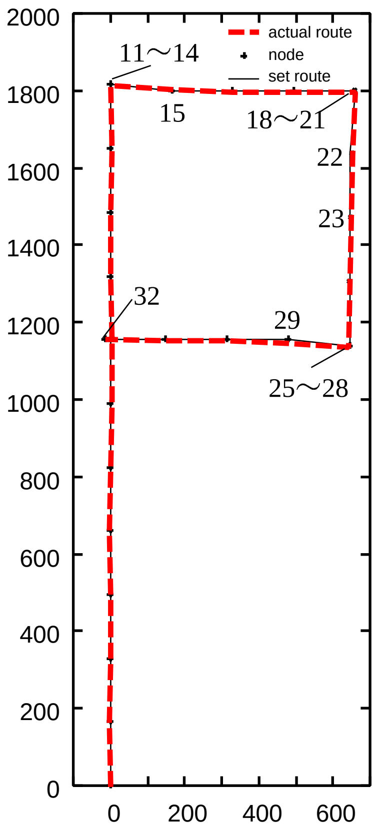


Figure 9: The set nodes and the route in the autonomous run

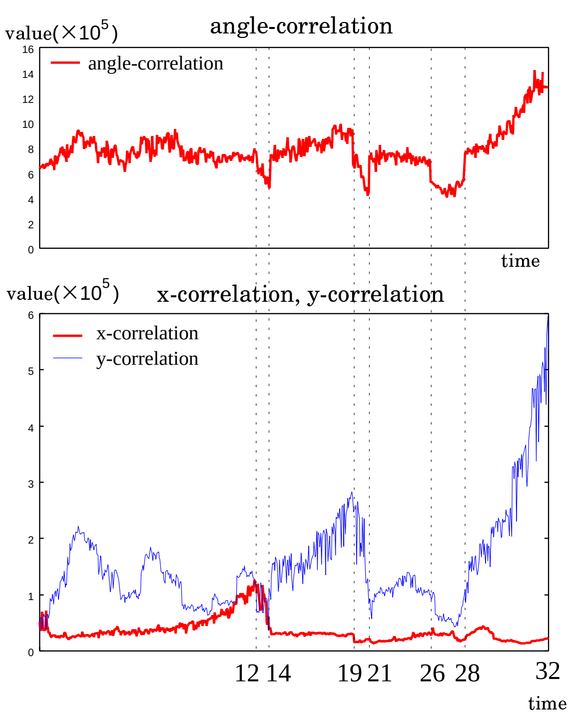


Figure 10: The correlation of the orientation and the position

Table 3: Navigation and localization error at each node

Node No.	Navigation Error [cm]	Localization Error [cm]
0	0	0
1	-2	2
2	0	4
3	0	0
4	-2	2
5	2	0
6	3	1
7	3	0
8	2	1
9	1	1
10	3	1
11	2	2
15	-5	1
16	0	1
17	0	1
18	1	1
22	-8	3
23	-6	6
24	-1	2
25	4	3
29	-6	6
30	-1	0
31	1	1
32	3	3

Table 4: Average and maximum value of navigation and localization error

	[cm]
Average Navigation Error	2.8
Maximum Navigation Error	12
Average Localization Error	2.2
Maximum Localization Error	14

the average and maximum value of navigation and localization errors in the nodes. These values were sufficiently small to perform autonomous navigation in such an environment.

Experiment of Navigation in the inverse direction

The experiment of an autonomous navigation in the inverse direction using the node scan of 360 degree was conducted. The route for the navigation and the arrangement of nodes are the same as shown in **Figure** 7. After building a sequence with scans of 180 degrees under manual navigation, autonomous recording run using the autonomous navigation the scan sequence was performed to build a sequence of scans of 360 degrees. **Figure** 11 shows the set of nodes and the route in the autonomous inverse run. It is shown that the localization and the navigation was performed well from node No.32 to No.2. **Figure** 12 shows the correlation values between the current scan and the node scan the orientation θ and the position x and y in the experiment. At nodes No.1 and 0, all correlation values was too low, which indicated the robot failed in the localization. The

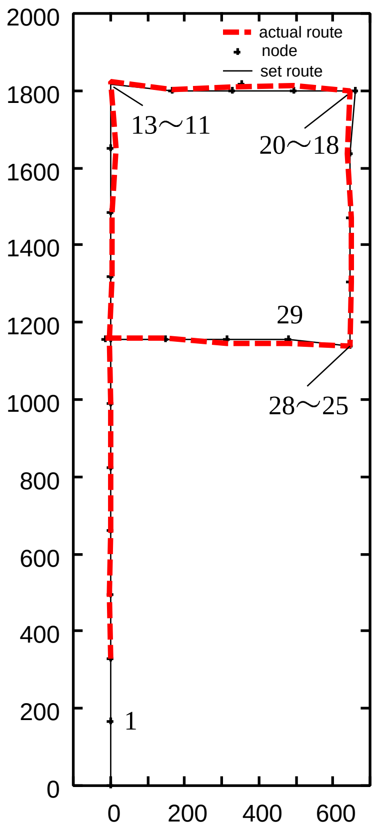


Figure 11: The set nodes and the route in the autonomous inverse run

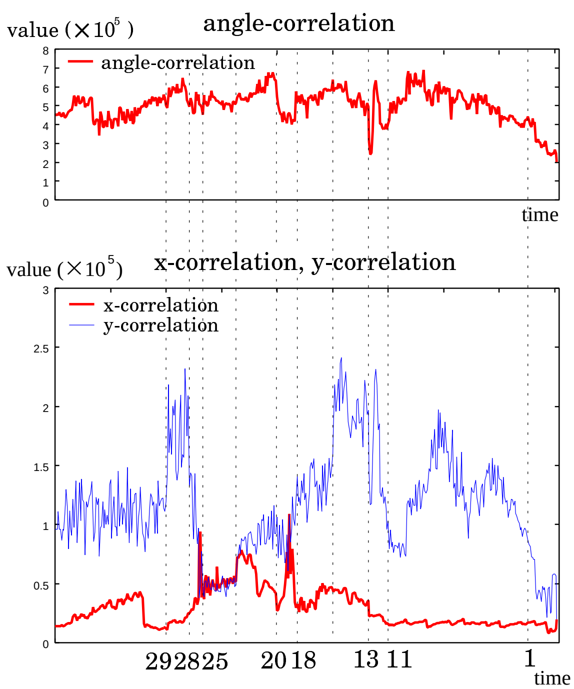


Figure 12: The correlation of the orientation and the position in the inverse run

Table 5: Average and maximum value of navigation and localization error in the inverse run

	[cm]
Average Navigation Error	5.5
Maximum Navigation Error	15
Average Localization Error	5.8
Maximum Localization Error	17

reason is that in the autonomous recording run the node scans of 360 degrees cannot be acquired well since there was not sufficient features around these nodes.

Table 4 shows the average and maximum value of navigation and localization errors. Though these values of average are larger than the ones of normal direction, the navigation was successfully performed.

4 Summary

We proposed a novel navigation method for a mobile robot using a laser range finder based on the memory-based approach. A robot memorizes sequential scanning data of the laser range finder in the recording run. Then the localization of the robot is achieved based on the matching between the current scan and memorized scan sequence in the autonomous run. Experimental results of the recording run and the autonomous navigation both in the normal direction and in the inverse direction was presented to show the feasibility of the proposed method.

As the future works, we are going to integrate other sensory information to cope with the environment with less features because the proposed matching method requires flat walls which have different directions. We are also going to implement speech recognition function on the robot to achieve natural communication with the visitors.

References

[1] C. Stanfill and D. Waltz. Toward memory-based reasoning. *Communications of the ACM*, 29(12):224–262, 1986.

[2] Y. Matsumoto, M. Inaba, and H. Inoue. Visual navigation using view-sequenced route representation. In *Proceedings of IEEE International Conference on Robotics and Automation*, pages 83–88, 1996.

[3] Y. Matsumoto, M. Inaba, and H. Inoue. View-based approach to robot navigation. In *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 1702–1708, 2000.

[4] I. J. Cox. Blanche - an experiment in guidance and navigation of an autonomous robot vehicle. *IEEE Transactions on Robotics and Automation*, 7(2):193–204, 1991.

[5] J. Gutmann, T. Weigel, and B. Nevel. Fast, accurate, and robust self-localization in polygonal environments. In *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 1412–1419, 1999.

[6] G. Weiss, C. Wetzler, and E. V. Puttkamer. Keeping track of position and orientation of moving indoor systems by correlation of range-finder scans. In *Proceedings of IEEE International Conference on Intelligent Robots and Systems*, pages 595–601, 1994.