Autonomous Mobile Robot System for Long Distance Outdoor Navigation in University Campus

Shoichi MAEYAMA, Akihisa OHYA and Shin'ichi YUTA
Intelligent Robot Laboratory
Institute of Information Science and Electronics
University of Tsukuba
Tsukuba, Ibaraki, 305 JAPAN
phone:+81-298-53-5155 fax:+81-298-53-6471
Email:maeyama@roboken.is.tsukuba.ac.jp

Keywords : Development of an autonomous mobile robot, Outdoor navigation and Execution monitor.

Abstract

We are developing a self-contained and autonomous mobile robot to navigate itself in our university campus. In this paper, we discuss on the important issues to realize the robot which has an intelligence and robustness for outdoor navigation. Then, we report our mobile robot "YAMABICO NAVI", which is integrated many functions such as locomotion, position estimation and sensors to detect landmarks and obstacles as an example of such a robot. Furthermore, we also describe an execution monitoring tool for observing the internal state of the robot while outdoor experiments.

1 Introduction

Our research interest is to realize a long distance outdoor navigation of a mobile robot.

The target environment is the paved or tiled pedestrian walkway in our university campus. The pedestrian walkway can be assumed to be a two dimensional plane. It is along with walls, hedges or trees, which can be utilized as landmarks for estimating the robot position.

The robot should be a self-contained autonomous mobile robot. The size is better to be smaller than child for the safety in experiments. The speed should be not too slow than human walking and the speed of 30[cm/s] is required. The robot has to have sensors to detect landmarks and obstacles.

The target task is 1.5[km] navigation from the front of the building of our laboratory to the dormitory center which is located at the end of our campus, shown in Figure 1. The photographs of the target environment are shown in Figure 2.

Our approach to realize this task is the position based navigation using Perceived Route Map (PRM). In this approach, a human operator controls the robot to the goal at first (Route teaching stage). The robot remembers its own trajectory as a path and the location of landmarks to correct its position on the way to the goal. The autonomous navigation is performed by playback of the generated PRM (Playback navigation stage). The idea of this method is illustrated in Figure 3. In this method, The operator teaches only the course from the start to the goal with manual controller. The robot generates the route map which is perceived by own sensors. The robot continuously navigates itself to the goal by feedback control of the estimated position by dead reckoning, to follow the path in the PRM and occasionally correcting its position by fusion of the positional information obtained from landmark recognition.

In this paper, we report how to develop the robot for realizing a such given task. We also describe the execution monitoring tool for observing the internal state of the robot for software development.

2 Important issues on realizing a robust mobile robot

The important issues to develop the robust mobile robot which performs the task given above are discussed in this section. To realize a such navigation task, the various functions must be developed, improved and integrated on the robot. The outdoor environment along the long distance path includes a various conditions. At the beginning of the development, essential issues for achieving this task was ambiguous. For instance, we did not know how much landmarks are necessary and what kind of landmark is useful in the target environment. These elements has gradually been obvious with the progress of the research. So, the robot must be developed and improved incrementally.

Many functions such as a locomotion control or sensors must be developed. Each function might be developed by different researcher who is a specialist on each field. Each function module should be used as black box. But, the algorithm working in each module must be transparent. Modularity and transparency are key issue to develop a complex system by integrating many functions developed through the distributed research. Each function would be improved gradually and independently. So, most important subject in realizing the navigation system is integration of each function. On the other word, it is exactly the research of navigation to integrate the mobile robot. How to integrate and how to maintain each function are the dominant subjects in the research of navigation system.

Not only the robot itself but also the developing environment is important issue in the research. By only watching the out-look of the behavior of the robot, it is sometimes difficult to find the reason of the unexpected motion. The internal state of the robot such as the flow of the program (what the robot wants to do) or the estimated position (where the robot estimates own location) must be observed by human with the execution monitoring tool. However, the self-contained and autonomous mobile robot does not have enough power and space for the display. Remote brain approach is proposed to overcome such a problem [1]. But, it is not available for the long distance navigation in real environment because the robot body has to be near enough to the host to communicate each other in the remote brain approach. For the navigation task, all computational power should be self-contained to move in large area. And, the programing and debugging environment should be separated from robot for the limited power and weight conditions. The minimum set of the monitor to observe the internal state of the robot should be carried by the human operator.

Consequently, important issues on realizing the robust mobile robot is the distributed developing and incremental integration. The execution monitoring tool for debugging is also very important. In next section, we introduce our mobile robot, which is developed by this approach.

3 Development of the mobile robot YAMABICO NAVI

3.1 The YAMABICO NAVI robot

We have more then 20 mobile robot platforms for the experimental research of the autonomous robots. Family name of these robots is YAMABICO. The YAMABICO NAVI shown in Figure 4 is one for outdoor experiments, which has the wheels with larger radius and width than our standard YAMABICO for indoor applications. This robot has two wheels driven by two DC motors with encoders. It contains a valve regulated lead acid battery (12V 7Ah) on the body. Beside the four wide range sonar, we implemented the another sonar produced by Polaroid corporation and small size TV camera, both on the turn table controlled by stepping motor. There is a controller with six CPU modules connected with the Y-BUS II which is the low power system designed by our research project.

3.2 The architecture of controller for the YAMABICO robot

The controller for the YAMABICO robot has the central decision making and functionally distributed architecture[2]. The structure of YAMABICO NAVI is illustrated in Figure 5. Total coordinated control is carried out on the center module called MASTER. The MASTER and the other function modules are connected as star via DPM : Dual Ported Memory. The MASTER controls the robot total behavior by giving the commands and getting the information from function modules. Each function modules does its best to realize the request from the MASTER by commands and post the current state on the state information monitoring panel which is allocated on the DPM. The MASTER always watches the state of each module and decides the next robot motion to issue the commands.

3.3 Distributed Function modules

Each function module is independently developed. When the refined function module is realized, it is integrated to the robot. So, the current robot is the set of the most refined modules in the state of the art. We explained the function modules integrated on the YAMABICO NAVI. They are Locomotion controller[3], Position estimator[4][5], Landmark detection sensors[6], Obstacle detection sensor[7] and Voice synthesizer[8].

3.3.1 Locomotion controller : SPUR

The trajectory is controlled to follow the specified straight line by feedback of the estimated position on the consideration of the dynamics of the robot. The stop position is also controlled.

3.3.2 Position estimator : POEM III

The position and its uncertainty are always estimated in this module based on EKF : Extended Kalman Filtering. The positional uncertainty is always calculated by dead reckoning. And, when the command is given based on the external sensor and map information, POEM III fuses these data by MLE : Maximum Likelihood Estimation to correct the cumulative error of dead reckoning by fusion of dead reckoning and landmark recognition.

3.3.3 Landmark detection sensors : SONIC and IS EYE

SONIC is the processor to calculate the distance obtained from sonar. IS EYE is the image processor to capture the image with two frame memory area. For outdoor navigation, the agent to find trees is implemented. It calculates the direction to the tree from the captured image based on the distance and the tree model.

3.3.4 Obstacle detection sensor : SONIC

The measurement by the front side sonar is used for obstacle detection. Obstacles such as a human is detected up to 150[cm] by this sensor.

3.3.5 Voice synthesizer : VOICE

The message requested from the MASTER is spoken. Decimal and hex number is synthesized[9]. The sentence represented by ROMAN letters is also synthesized. The recoded voice by ADPCM[10] is played back. This module is used for telling own internal state by robot itself. It is spoken what the robot wants to do now, why the robot is now stopping and so on.

3.4 Coordination control by MASTER

Various program is written on the MASTER which uses the command of function modules. The role of the program on the MASTER module is to make decision of the robot motion based on the coordination of all functions of the robots. The distributed and incremental development is also expected. So, we developed and implemented the agent to decide next path and the agents to detect landmarks. These agents are integrated on the MASTER. The path is determined by only one agent because the behavior of the robot must be consistently managed and controlled serially at time axis. On the other hand, the landmark recognition processes are working in parallel. To get a good solution, many candidate must be considered simultaneously.

To realize a robust navigation, it is important that the robot can acquire the redundant landmark information. So, we show below, how to develop a robust landmark recognition system by distributed developing and incremental integration of multiple landmark agents.

3.4.1 Path Agent

In the route teaching stage, this agent observes the route taught by human and records it to Path Map.

In the playback navigation stage, it gets the path from Path Map and send the locomotion control command to SPUR. It also observes the obstacle to the heading direction. When an obstacle is detected, it send the Stop command to SPUR. Only this agent send the command to SPUR.

3.4.2 LmA : Landmark Agent

In the route teaching stage, each LmA searches each specified landmark in parallel. When it finds the landmark candidate, it tracks the candidate. If it can track the candidate for a certain distance. it records the location and sensing point of the candidate to each LmA Map. For example, Hedge-LmA is one to detect hedges as landmarks when the distance measured by sonar is almost same distance while traveling over 90 [cm]. Tree-LmA is one to detect trees as landmarks when the tree is detected at the almost same location by Polaroid sonar and small TV camera (SONAVIS[6]) while traveling over 60 [cm]. Here, Sonavis Agent is one to arbitrate Hedge LmA and Tree LmA, since these two Landmark Agent use the same sensor property SONAVIS. Since these more than two LmA use the same actuator, the arbitration agent is necessary.

In the playback navigation stage, each LmA looks for the landmark in LmA Map when the robot arrives at the sensing point. If the landmark location measured by sensor is inside of 1σ error ellipsoid, this measurement is sent to POEM III and the estimated position is automatically corrected.

4 Execution monitor and manual controller

It is important and difficult for autonomous mobile robot to monitor the internal information such as the current state of execution and recognition. Of course, voice module is usefully used for monitoring such data. It is very useful to check the program flow. However, it has not enough bandwidth and is difficult to understand the geometrical location between path and landmark estimated in the robot from operator. So, we developed the graphical execution monitor as monitoring and debugging tool. We show our execution monitor in outdoor experimental environment and manual controller for route teaching in this section.

4.1 The cart for outdoor experiments

Figure 6 shows the cart to carry the robot and necessary equipments for outdoor experiments.

The down stage is a place for the robot. The second stage has the execution monitor, radio controller which can manually control the velocity and heading direction of the robot and TV monitor to watch the result of image processing sent from the robot by UHF.

4.2 The execution monitor

For our research, we developed the execution monitoring system in the route teaching stage and the playback navigation stage. Sparc Book note computer is used as the hardware. The monitoring information in two cases of route teaching stage and playback navigation stage are shown here.

4.2.1 Route teaching stage

During the route teaching stage, raw data of landmark measurements and current robot position are indicated on the graphical display of the execution monitor. After the route teaching, all information of the PRM (Path and Landmarks) can be checked. The graphical drawing of the PRM is shown in Figure 7. The upper right window of this figure shows the path from A to G in Figure 1. Then, the rectangle area of the upper right window is zoom up to the main window. In the main window, the operator can watch the path, sensing points and the acquired landmarks such as trees and hedges.

4.2.2 Playback navigation stage

During the playback navigation stage, robot position and error ellipse and raw data of landmark measurements are observed on the execution monitor display. After the playback navigation stage, the trajectory in this stage and the path in PRM can be compared in the display as shown in Figure 8. This figure shows the example of the position correction by hedge. From this figure, we can observe that the robot returns to the expected path by following the corrected path after correcting the position.

5 Conclusions

We are now developing a self-contained and autonomous mobile robot for long distance outdoor navigation. The robot for realizing a long distance navigation must be integrated many functions such as locomotion control, position estimation, landmark recognition and obstacle detection. In this paper, we pointed the necessity of distributed developing and incremental integration for realizing a mobile robot. We describe our robot developing based on our proposed approach. Functional(lower) level of this robot are modularized at the unit of hardware module (controller board). Total coordination (higher) level are modularized at the unit of software module (agent process). We believe this approach makes it possible to develop a mobile robot with highly navigation ability.

We will continue the development of the robot to realize a robust long distance outdoor navigation. Through improving our robot based on many experimental results, we will invent more refined integration technique of many functions.

References

[1] M. Inaba, S. Kagamin and H. Inoue, "Real-time Vision plus Remote-Brained Design open New World for Experimental Robotics", Experimental Robotics IV, Springer, 105-113, 1997.

[2] S. Yuta and J. Iijima, "The architecture for an autonomous mobile robot controller", Proceedings of the 8th academic conference of Robotics Society of Japan, 967-970, 1990 (in Japanese).

[3] S. Iida and S. Yuta, "Vehicle command system and trajectory control for autonomous mobile robots", Proceedings of IEEE/RSJ International Workshop of Intelligent Robots and Systems, 212-217, 1991.

[4] S. Maeyama, A. Ohya and S. Yuta, "Non-stop outdoor navigation of a mobile robot - Retroactive positioning data fusion with a time consuming sensor system -", Proceedings of IEEE/RSJ International conference on Intelligent Robots and Systems, vol.1, 130-135, 1995.

[5] Shoichi Maeyama, Nobuyuki Ishikawa and Shin'ichi Yuta, "Rule based filtering and fusion of odometry and gyroscope for a fail safe dead reckoning system of a mobile robot", 1996 IEEE International Conference on Multisensor Fusion and Integration for Intelligence Systems, 541-548, 1996.

[6] S. Maeyama, A. Ohya and S.Yuta, "Positioning by tree detection sensor and dead reckoning for outdoor navigation of a mobile robot", Proceedings of IEEE International conference on Multisensor Fusion and Integration for Intelligent systems, 653-660, 1994.

[7] T. Ohno, A. Ohya and S. Yuta, "A new ultrasonic transmit and receive circuit for improvement of range finding performance", Proceedings of the 12th academic conference of Robotics Society of Japan, 1093-1094, 1994 (in Japanese).

[8] S. Maeyama, A. Ohya and S. Yuta, "Voice system for debugging the behavior program of autonomous mobile robots", Proceedings of Intelligent Mobile Robot Symposium'94, 154-155, 1994 (in Japanese).

[9] "VOTRAX SC-02 Phoneme Speech Synthesizer", VOTRAX, INC.

[10] "OKI'92 OKI Semiconductor IC circuits — Voice LSI", OKI ELECTRONIC DEVICES (in Japanese).

Caption list

Figure 1 : Schematic map of target environment (A,B, $\cdots$,G,I are passing points.)

Figure 2 : Photographs of the target environment

Figure 3 : Perceived Route Map (PRM) generation by natural landmarks acquisition through human route teaching and autonomous navigation using the generated PRM

Figure 4 : Photograph of the YAMABICO NAVI robot (The dimension (W x H x D) is about 450 x 600 x 500 [mm]. The weight is about 12[kg]. The wheel diameter is about 150[mm]. The tread is about 400[mm].)

Figure 5 : System configuration of the YAMABICO NAVI robot by multiple agents

Figure 6 : The cart as a developing and debugging environment for outdoor experiments (There is a place of the robot on the first floor. There is a graphical execution monitor, TV monitor and manual controller on the second floor.)

Figure 7 : The acquired path and landmarks after route teaching stage in graphical display of execution monitor

Figure 8 : The data after the playback navigation stage compared with the data in PRM

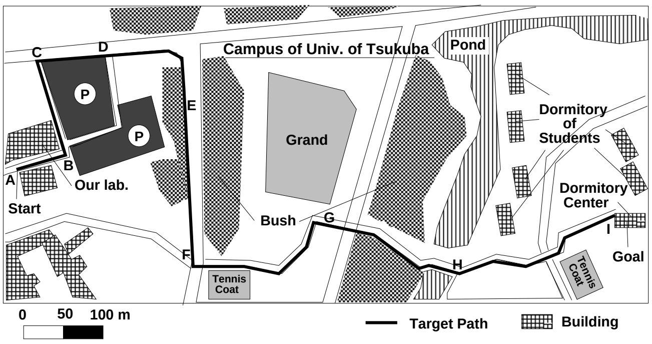

Figure 1: Schematic map of target environment (A,B, ···,G,I are passing points.)

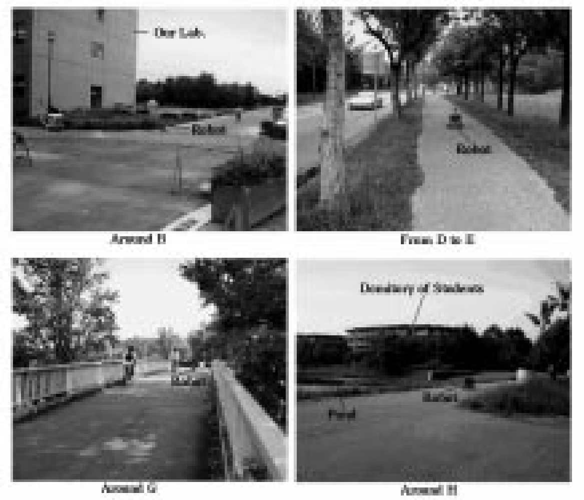

Figure 2: Photographs of the target environment

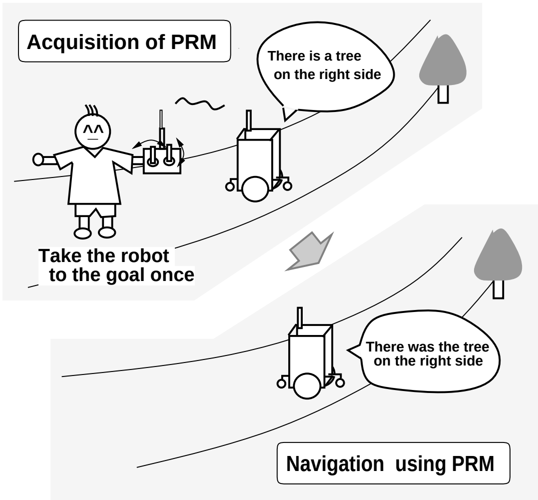

Figure 3: Perceived Route Map (PRM) generation by natural landmarks acquisition through human route teaching and autonomous navigation using the generated PRM

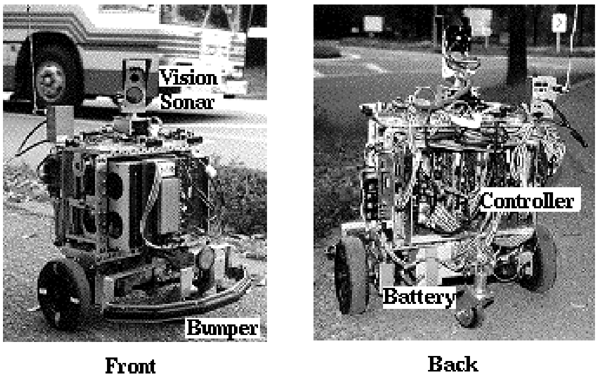

Figure 4: Photograph of the YAMABICO NAVI robot (The dimension (W x H x D) is about 450 x 600 x 500 [mm]. The weight is about 12[kg]. The wheel diameter is about 150[mm]. The tread is about 400[mm].)

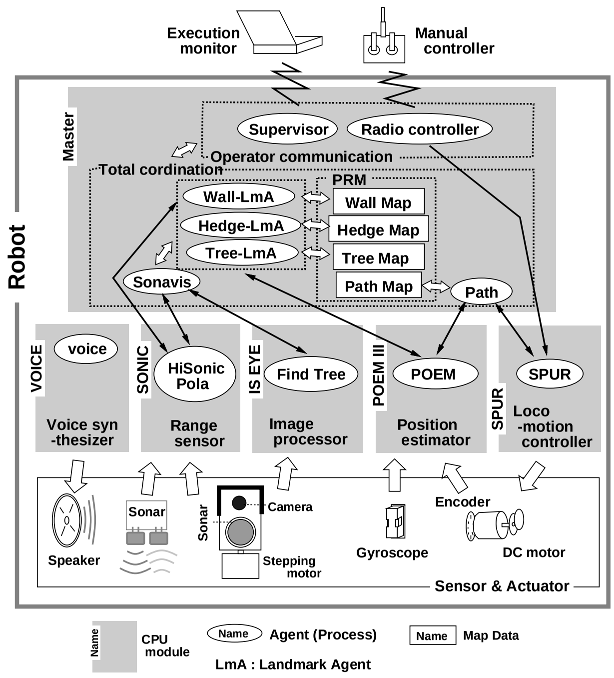

Figure 5: System configuration of the YAMABICO NAVI robot by multiple agents

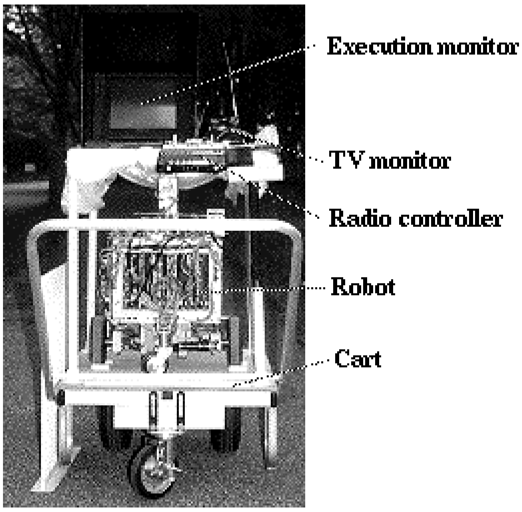

Figure 6: The cart as a developing and debugging environment for outdoor experiments (There is a place of the robot on the first floor. There is a graphical execution monitor, TV monitor and manual controller on the second floor.)

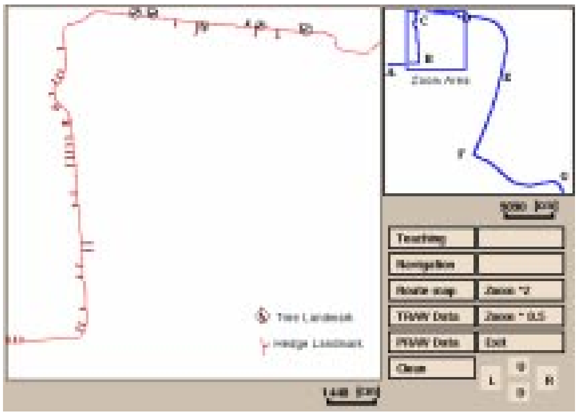

Figure 7: The acquired path and landmarks after route teaching stage in graphical display of execution monitor

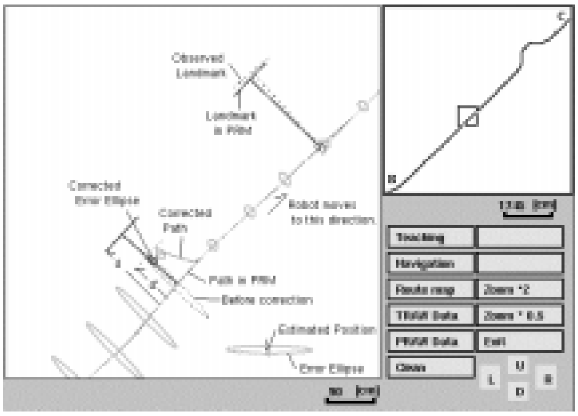

Figure 8: The data after the playback navigation stage compared with the data in PRM