Outdoor landmark map generation through human assisted route teaching for mobile robot navigation

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Abstract

We present research on long distance outdoor navigation based on the estimated position for a mobile robot. In this paper, we discuss the generation of the route map given to the robot in advance of an autonomous navigation. We propose how the robot generates the route map including landmarks while a human operator takes it to the goal once. By our proposed method, it will be easy to make a large size route map for long distance outdoor navigation.

1 Introduction

When a human being moves to a goal, he uses perception by vision rather than the estimated position. Therefore, there are many approaches for vision based robot navigation[1][2]. The reason why a human being moves based on vision is that he has very powerful visual perception supported by much knowledge of the environment. The robot, however, does not have enough knowledge of the environment within the limits of the processing power, the capacity of memory and the ability to manage some knowledge. On the other hand, the robot can measure the amount of movement precisely. Especially, odometry which calculate a position from the accumulation of wheel rotation is very reliable when the wheel rotation is controlled based on the consideration of its dynamics. Of course, odometry has the cumulative error of the estimated position. This error must be compensated by observation of a landmark. On the condition that the robot knows the correct position approximately, the observation of a landmark does not result in a fatal misunderstanding of the landmark. Consequently, the robust navigation of a mobile robot can be achieved even if the robot does not have much knowledge in comparison with a human being. We have already made some experiments of estimated position based outdoor navigation with a route map which includes the path from the start to the goal and location of landmarks[3][4]. As a result, we confirmed that the robot could navigate a few hundred meters robustly, when the robot manages the estimated position and the error covariances, and occasionally corrects these estimated variables by the observation of a landmark. We hope that the robot can navigate much longer distances. However, it is difficult for a human to make a long distance map and give it to the robot. In this paper, we propose how a robot can generate a large size route map for long distance outdoor navigation for itself after a human operator takes it to the goal with a manual controller once.

2 Problem definition

The target environment is the paved or tiled pedestrian walkway shown in Figure 1. The pedestrian walkway can be assumed to be a two dimensional plane along with a wall, a hedge or a tree etc, which can be utilized as landmarks for correcting the position. These landmarks can be represented as line segments or points on a two dimensional plane. These expressions are very friendly for Kalman filter based positioning[4][5]. The robot is assumed to be a self-

Figure 1: Target environment which has a paved road along with trees and hedges

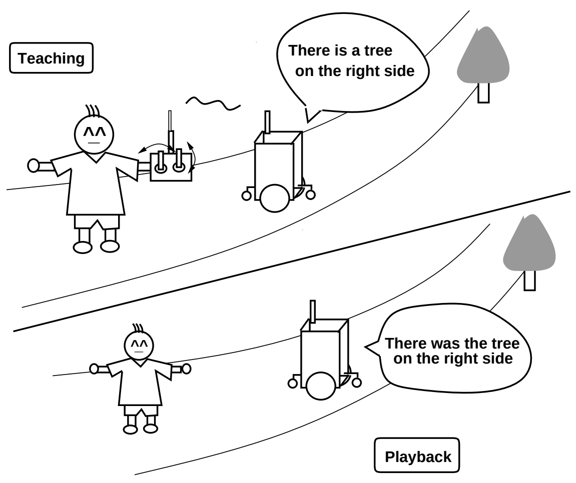


Figure 2: Teaching and playback navigation

contained autonomous mobile robot. The speed of the robot is assumed to be about 30cm/s. The robot is assumed to have sensors to detect a landmark and detect an obstacle. A walking person or a bicycle can be assumed to be a mobile obstacle. In response to the these mobile obstacles, the robot waits for them to go away, because the speed of the robot is much slower than the obstacles. The objective of this research is the development of a robot to achieve long distance outdoor navigation over a distance of about 2kms in the target environment described above. In this paper, we focus on the self-generation of large route map for position based long distance outdoor navigation.

3 Teaching and playback navigation

We name the proposed method in this paper *teaching and playback navigation*. Teaching and playback navigation has two stages. The first stage is *teaching*. At this stage, a human operator takes the robot to the goal (*route teaching*). Then, 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 operator teaches only the course from the start to the goal with manual controller. The second stage is *playback*. In this stage, the robot navigates to the goal based on the position, while playing back the path recorded in the teaching stage and occasionally correcting its position by the observation of the landmarks. It is similar to a mother that tells her child the way to school. When she takes him to school once, he remembers the path and the landmarks on the way to school. Then, he can go to school by himself.

4 Requirements on a behavior programing for route map generation

Route map generation assisted by human operator is accomplished by the cooperation of human route teaching and autonomous landmark detection. Various landmarks must be recognized to navigate long distance in which various environment is included. The robustness of position based navigation is determined by the reliability of landmark detection. However, It is not easy to realize the reliable detection of various landmarks . So, it would be gradually realized through many improvements and re-configuration of behavior program. We hope a programing to enable modifications and re-configuration many times without difficulty. Therefore, the requirements on a behavior programing are enumerated as follows : 1.Parallel, 2.Incremental, 3.Re-configurable, 4.Independent. Both reading an operator control and detecting a landmark must be processed in parallel. Capability of landmark detection should be incrementally increased and be deliberately selectable. Each process as a part of the program had better be independent each other because of easy maintenance We describe the program of route map generation by multiagents, which satisfies the above requirements in following section.

5 Route map generation by cooperation of human and robot

In the route map generation, the robot must look for landmarks while following the human operation. The behavior program for the route map generation is realized by parallel execution of multiprocess. We call each process an agent which is assigned each specified task[6]. Pilot agents and Landmark agents compose the map generation program (Figure 3). They generate route map separating Path map and LmA map.

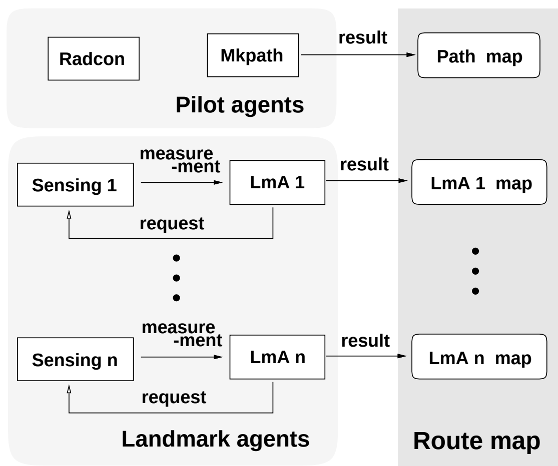


Figure 3: Multiagent programing for route map generation (*Radcon* interprets human operation at the constant interval. *mkpath* records the passing points to Path map at the constant interval. *LmA* is a landmark agent which looks for an assigned landmark and stores the detected landmark to the LmA map. *Sensing* controls a sensing direction and get the sensing results.)

5.1 Pilot agents

Pilot agents control a locomotion by interpretation of human operation and remember the passing points every constant interval. The kind of manual controller can be selectable by only changing *Radcon* in Figure 3. *Mkpath* records the passing points from the start to the goal, independent of *Radcon*

5.2 Landmark agents

Landmark agents is the gathering of *LmAs* and *Sensing agents*. The set of LmA and Sensing agent detects a specified landmark. Each LmA looks around the environment and looks for an object observable with Sensing agent. Once the LmA finds a candidate of landmark, the LmA starts tracking it. By tracking, the LmA can eliminate mobile obstacle, reduce measurement errors and misunderstandings. The LmA remembers the sensing point, the location and the characteristics when the object is repeatedly observable at the same location even if the robot has a little displacement of its position.

Basic procedure of LmA to detect the landmark is shown in following sentences. At first, we define three states(*SLEEP, WAKEUP, TRACK*). *SLEEP* means no candidate of landmark. *WAKEUP* means that the candidate object as landmark is detected and the agent starts tracking it. *TRACK* means that the object is repeatedly detected two or more times. When the order of the state transition is SLEEP $\rightarrow$ WAKEUP $\rightarrow$ TRACK, the landmark is detected and recorded to LmA map The state transition is caused whether the current measurement is valid or not and whether the current landmark is the same as the previous landmark or not, as shown in Figure 4. What kinds of landmark are available in the target environment can be determined by the operator. The operator must prepare the required LmA in the program in advance of route teaching. However, the robot does not know where each landmark is. So, the robot must look for each landmark in parallel by using each LmA.

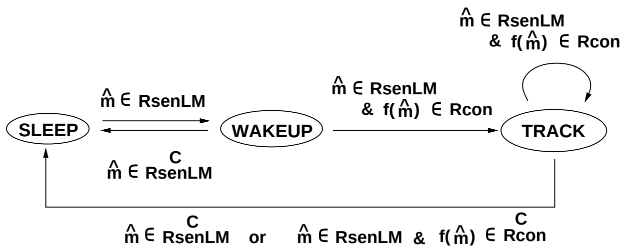


Figure 4: State transition of LmA (RsenLM is validation of the current measurement $\hat{m}$. Rcon is geometrical and characteristical condition to judge the same landmark. $f(\hat{m})$ is the landmark location calculated from $\hat{m}$.)

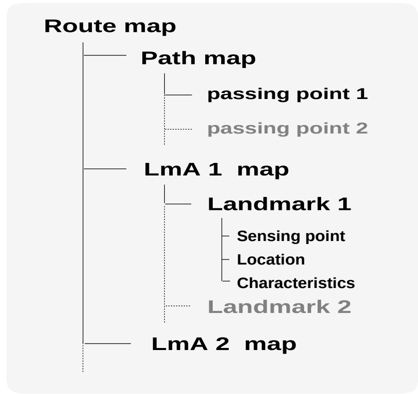


Figure 5: Route map representation separating Path map and each LmA map (Path map:Recording a passing point at the constant interval, LmA map:Recording a sensing point, landmark location and the characteristics)

5.3 Route map separating Path map and LmA map

As the result, route map is generated with the representation shown in Figure 5. The route map includes a Path map and each LmA map. In the navigation stage, Path map and each LmA map are respectively utilized by each agent for playback. Playback agent for Path map generates each line segment path and the robot speed calculated from one passing point and the next one. Playback agent for LmA map observes the robot position until the robot reaches to the sensing point. Then, the agent send the request to control the sensing direction to the sensing agent and receive the sensing results. At last, the robot corrects its position by using landmark and continues to navigate long distance[4].

6 Implementation of the robot system with Tree LmA

In this section, we describe an implementation of the robot system for teaching playback outdoor navigation with Tree LmA. Tree LmA is a kind of LmA, which can detect a tree along with the walkway shown in Figure 1. Tree LmA records the detected tree in TreeMap.

6.1 The YAMABICO NAVI robot

We implemented the system to execute the teaching and playback for outdoor navigation on the YAMABICO NAVI robot, which is one of the self-contained autonomous mobile robots developed by our research group. Figure 6 is the photograph of the YAMABICO NAVI robot. Figure 7 is the schematic structure of the YAMABICO NAVI. The controller of the YAMABICO NAVI is the central decision making and functional distributed architecture. Each rectangle corresponds to a hardware module with a CPU in Figure 7. Decision making is carried out on the hardware

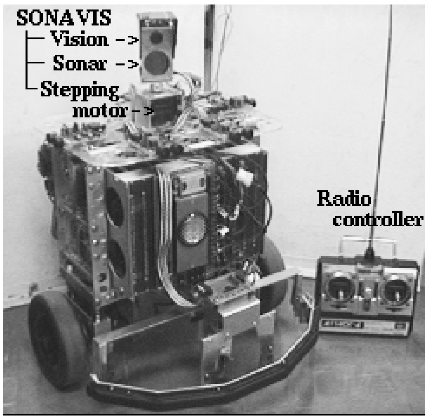


Figure 6: The YAMABICO NAVI robot for the teaching playback navigation robot system(to change the current robot)

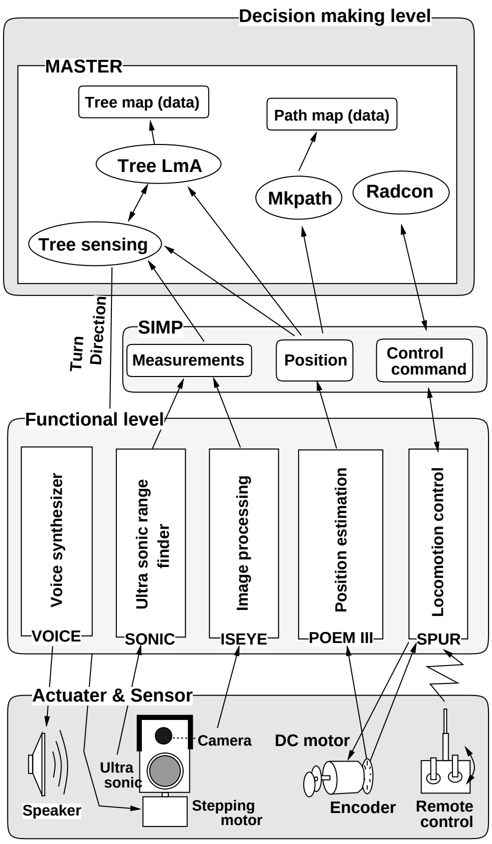


Figure 7: Schematic structure of the YAMABICO NAVI robot controllers (SIMP:State information monitoring panel)

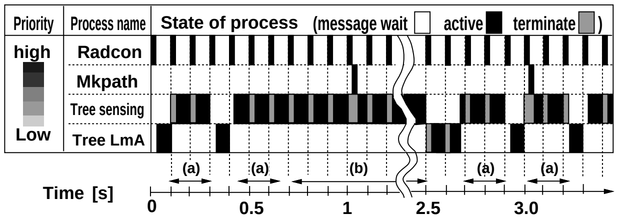


Figure 8: Time table switching multi-process as multi-agent: (a)waiting an measurement of ultrasonic range finder, (b)waiting an image processing

module called *MASTER*. The request of behavior decided by the master module is carried out by each functional module. Each functional module does its best to realize the request from the MASTER and post the current state on the state information monitoring panel(SIMP). MASTER watches the state of each module on the SIMP and decides the next robot motion.

6.2 System for route teaching

We implemented a route teaching system with a commercial proportional radio controller. The operator can control the robot speed and sterring. At first, *Radcon* interprets a human operation. Then, it sends the locomotion control command to SPUR module. Figure 8 shows the time table switching active agent. Radcon is processed every 100[ms]. *Mkpath* is processed every 1[s]. The rest time used by Landmark agents.

6.3 Tree LmA

Tree LmA can detect a tree which has the diameter of the trunk about 26cm. Trees are observed by the sensor combined with an ultrasonic range finder and vision on the turn table controlled by a stepping motor. This hybrid sensor is called SONAVIS in Figure 6 [3] Mesurements obtained from SONAVIS are the distance and the direction to the trunk of tree. Tree LmA sends Tree sensing agent the request of sensing direction decided by the status of LmA. If the status is SLEEP, the default turning pattern (50,30,-30,-50[deg]) is repeated. If the status is WAKEUP or TRACK, the next sensing direction is the direction of the landmark candidate detected in previous sensing. At first, tree sensing agent turn the SONAVIS to the requested direction. Then, the distance is measured by the ultrasonic range finder. When the distance is shorter than 350cm, the image is captured. If the tree is detected in the image, the direction to the tree is calculated from the center position of the trunk of the tree. Figure 8 shows the time table of the process of tree detection by Tree LmA amd Tree Sensing agent. Figure 9 shows the distance and image tracked by Tree LmA.

7 Experiments

We conducted some experiments of teaching and playback for outdoor navigation. The purpose of these

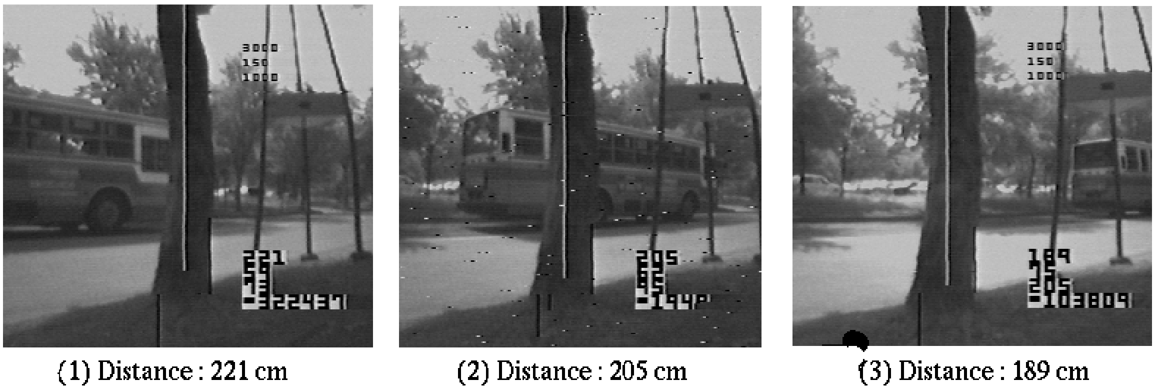


Figure 9: Tree tracking by Tree LmA(Vertical white line indicates the detected tree position in the image)

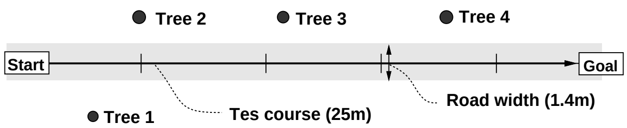


Figure 10: Experimental environment which has trees lined along with the paved walkway(The test course is the straight line 25m. There are four tees.)

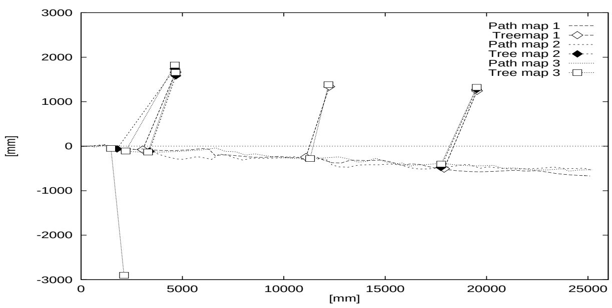


Figure 12: The generated route maps:Path map 1 and Tree map 1 indicate the routmap in the first trial. The points of Tree map indicate the pair of the sensing point and the landmark location.

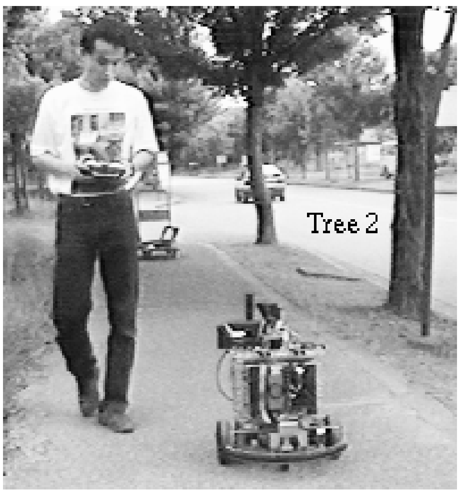
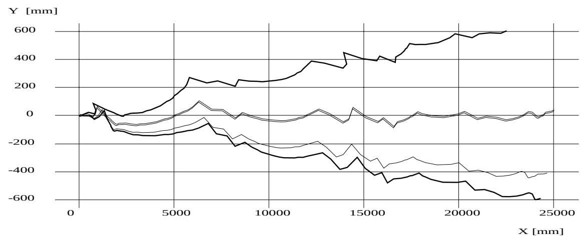
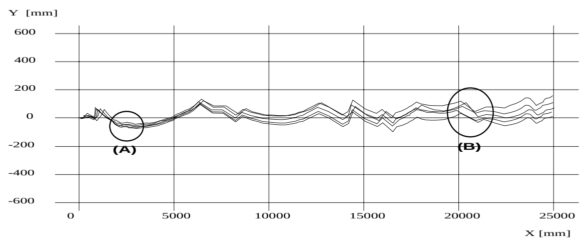


Figure 11: Photograph of route teaching (The operator has a radio controller in his hands.)

experiments is to understand how route map is generated by teaching and to confirm whether the robot can navigate with the generated map or not. Figure 10 shows the experimental environment which is the pedestrian walkway and has four trees suitable for landmarks. The test couse is the straight line 25[m]. In the first experiment, we took the robot along the test course from the start to the goal with radio controller. Figure 10 is the photograph of the robot and human operator with radio controller in his hands. During route teaching, the robot searches tree landmarks and remeber the locations in the Tree map. The generated maps in the trials of three times are shown in Figure 12. All generated pathes make a small curve to the right. These curves are caused by the systematic error of odometry which includes the measurement errors of wheel radius and tread, and the offset error of initial heading. Tree 2 and Tree 4 are always detected. However, Tree 1 is detected only in the thrid trial and Tree 3 is not detected in the second trial. The reason why tree 1 and tree 3 are sometimes lost is that the trunk of these trees is a little smaller than the one expected by Tree LmA. In the second, we experimented two kinds of playback navigation using Path map 3 and Tree map3. One is only playback of



(a) only odometry (without LmA)



(b) with Tree LmA

Figure 13: Comparison of the approximated real trajectory in the case of (a)only odometry and (b)odometry and Tree landmarks (Position is corrected by Tree landmarks around (A) and (B).)

Path map. It means that the robot uses only odometry. The other is playback of Path map and Tree map. Figure 13 is a comparison of these two playback navigations. Figure 13 (a) shows that the main error is the initial heading in the case of Path map playback. Because the systematic error of odometry in teaching stage is also replayed in the navigation stage. Therefore, the robot can run on the straight line by drawing the small right curve in his mind. Figure 13 (b) shows that the positional uncertainty coursed by the initial heading error is reduced by the correction using tree landmarks around (A) in Figure 13 (b). However, the error is remained at the goal. The remainder is caused by the error of the location data of tree 4 in the Tree map. The positional error can be reduced by using additional LmA.

8 Conclusions

We propose a teaching and playback outdoor navigation by multiagents programing. To confirm the performance of our proposed navigation, we conducted some experiements. As the results, I could confirm that the robot can navigate with the self-generated route map. Total advantages of our proposal are enumerated as follows.

1. Route map making without trouble
2. Overcoming the systematic error of odometory
3. Easy re-configuration of a behavior program
4. Gradual improvement for the robustness of positioning

However, the route map generated by robot is lower reliability and accuracy than one made by human. It rarely includes mismasurements of the landmark location and misunderstanding of landmarks. In future work, We will develop an algorithm which can gradually improve the route map information and overcome misunderstanding of landmark, and realize a robust long distance outdoor navigation.

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