MODIFIED LOCAL NAVIGATION STRATEGY FOR UNKNOWN ENVIRONMENT EXPLORATION

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Abstract: This paper presents an algorithm for unknown environment exploration based on the local navigation algorithm (LNA). The original LNA doesn't take into account the case in which the robots are trapped and stop exploring the environment. In this paper, we propose some modifications to overcome this problem and demonstrate it by using real robots. For validation purpose, we ran several experiments using the mini-robot Khepera II running on the Teleworkbench. The complete environment is divided into small quadratic patches with some objects placed in it representing obstacles. With on-board infrared sensors and wheel encoder, the robot can successfully explore the unknown environment. Moreover, by calculating the distance to surrounding patches, the implemented algorithm will minimize the distance traveled, and in turn of the consumed energy and time. This paper also shows the advantage of using the Teleworkbench for performing experiments using real robots.

1 INTRODUCTION

Exploration of unknown environments is one of important problems in robotics. The goal of the exploration task is to cover the whole environment in a minimum amount of time or with minimum consumed energy depending on the application. Exploration approaches focus on guiding the robot efficiently through the environment in order to build a map. Exploration algorithms using either a single or a multi-robot system based on simulations have been studied extensively in the past (Stachniss, 2006, Simmons, 2000, Manolov, 2003, and Burgard, 2000). In this paper we present the result of the implementation of local navigation algorithm (LNA) for environment exploration as introduced in (Manolov, 2003, Amin, 2007). We also modify the LNA to solve the problem of trapped robot so that it can explore the whole environment successfully independent of its shape and the position of the obstacles. Moreover, we use the distance of the neighbouring patches relative to the current robot position to further improve the algorithm. We also demonstrate the implementation of the modified algorithm using the mini-robot Khepera II. Furthermore, we demonstrate the advantage of using the Teleworkbench (Tanoto, 2005) as a test bed for performing and analysing experiments with real robots. For experiment analysis, we have developed a graphical analysis tool based on the MPEG-4 video standard (Tanoto, 2006). This tool allows us to record a video of the experiments together with experimental data and to visualize the internal and external behaviour of robots.

The paper is organized as follows: after presenting related work, Section 3 describes the LNA for unknown environment exploration and its limitation. Our modified algorithm (MLNA) is presented in Section 4. After that we present a comparison result between the two algorithms using the mini-robot Khepera II on the Teleworkbench. Finally, Section 6 concludes the paper.

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2 RELATED WORK

Exploration is the task of guiding a vehicle in such a way that it covers the environment with its sensors. Efficient exploration strategies are also relevant for surface inspection, mine sweeping, or surveillance (Choset, 2001). In the past, several strategies for exploration have been developed. One group of approaches deals with the problem of simultaneous localization and mapping (Bourgoult, 2002). A common technique for exploration strategies is to extract frontiers between known and unknown areas (Edlinger, 1994, Yamauchi, 1999) and to visit the nearest unexplored place. These approaches only distinguish between scanned and un-scanned areas and do not take into account the actual information gathered at each view-point. To overcome this limitation (Gonzales, 2001) determine the amount of unseen area that might be visible to the robot from possible view-points. To incorporate the uncertainty of the robot about the state of the environment (Moorehead, 2001) and (Bourgault, 2002) use occupancy grids (Hans, 1985) and compute the entropy of each cell in the grid to determine the utility of scanning from a certain location. (Whaite, 1997) present an approach that also uses the entropy to measure the uncertainty in the geometric structure of objects that are scanned with a laser range sensor. In contrast to the work described here they use a parametric representation of the objects to be scanned. (Edlinger, 1994) developed a hierarchical exploration strategy for office environments. Their approach first explores rooms and then traverses through doorways to explore other parts of the environment. (Tailor, 1993) describe a system for visiting all landmarks in the environment of the robot. Their robot maintains a list of unvisited landmarks that are approached and mapped by the robot. (Dudek, 1991) propose a strategy for exploring an unknown graph-like environment. Their algorithm does not consider distance metrics and is designed for robots with very limited perceptual capabilities. Recently, Koenig has shown, that a strategy, which guides the vehicle to the closest point that has not been covered yet, keeps the travelled distance reasonably small (Koenig, 2001). However, as experiments reported in this paper illustrate, such techniques can lead to a serious increase of measurements necessary to build an accurate map if the robot is not able to incorporate measurements on-the-fly while it is moving. This might be the case, for example, for robots extracting distance information from camera images.

3 LOCAL NAVIGATION STRATEGY FOR ENVIRONMENT EXPLORATION

The exploration strategy has to ensure that the complete area is explored. The LNA computes only the next step for moving. The computation is dependent on the area around the robot (Manolov, 2003).

The exploration algorithm works as follows. The complete environment is divided into small quadratic patches. The robot starts the exploration from any position in the environment. It can move between patches in all directions (east, west, north, south, and diagonal). When the robot visits a certain patch, it is considered to be analyzed. For the computation of the next movement, an algorithm is used to determine the costs of reaching each free patch around the robot. The cost function ***C*** for a free patch ***P*** is given as:

$$C(P) = N(P) \tag{1}$$

Where *N (P)* is a function that computes the number of free neighbouring patches around patch *P*. A visualization of the evaluation is given in Figure 1. After evaluating the cost for all free patches around the robot, the robot moves to the patch with the lowest cost that has the lowest number of neighbours and which is therefore most unlikely to be reached again in the future (Manolov, 2003).

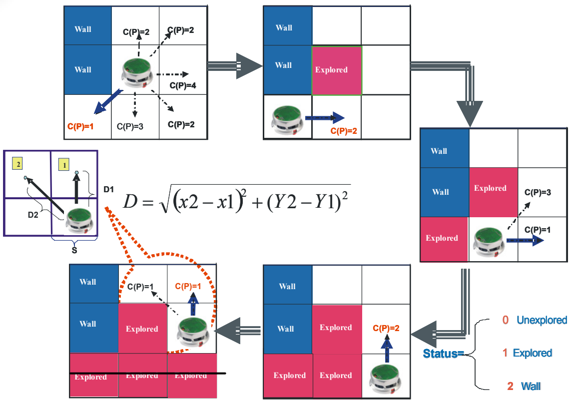


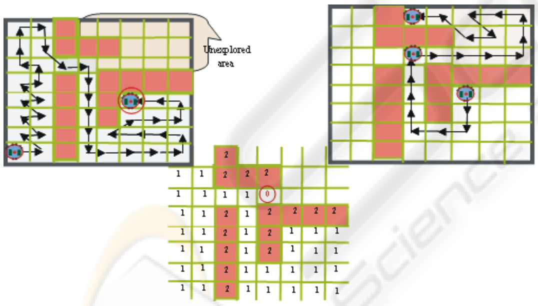
Figure 1: The algorithm determines for each free patch around the robot the costs *C* to reach it. The costs of all neighboring patches are different. Two patches have the same cost. The distance between the robot and the neighboring patches which have the same minimum costs (patch 1 and patch 2).

However, it is possible that there exist more than one patch with the same minimum cost. To solve this problem, we improve the algorithm by taking also into consideration the distance between the robot and each one of these patches, and then select the patch with minimum distance. Figure 1 illustrates the aforementioned situation.

4 THE MODIFIED LOCAL NAVIGATION ALGORITHM (MLNA)

LNA has a draw back that it can't ensure completeness in the case of a robot being trapped, e.g. when all of its neighbors are either obstacles or explored, and there is no free cell around to compute its cost. In this situation, it will simply stop and fails to complete exploring the whole environment as illustrated in Figure 2a.

We modified the algorithm to overcome this problem by calculating the shortest path to reach the unexplored area and continue exploring the environment. Our modified algorithm will determine the cost for reaching all the un-explored cells. We use the occupancy grid map in our algorithm to describe the environment. As illustrated in Figure 2b a cell can be in one of the following states which are represented by an integer number:



(a) (b) (c)

Figure 2: (a) the trapped robots Problem in LNA. (b) The map associated to the environment. (c) The shortest path that the robot follows to reach to the unexplored area and complete the exploration task.

Unexplored (0). No robot has been in the cell yet. As shown in Figure 2b, the cell with state 0 is detected by Khepera sensors as an unexplored free cell.

Explored (1). The cell has been traversed at least once by the robot, but it might need to go through it again in order to reach unexplored regions. It also means that the cell is free.

Wall (2). The cell cannot be traversed by the robot because it is blocked by an obstacle or a wall.

We had to differentiate between the explored cells that contain an obstacle and the explored cells that are empty, in order to be able to identify the back path of the robot successfully if required.

4.1 Cost of Reaching a Target Location

To determine the cost of reaching the Frontier cells, which are the cells between known and unknown areas, we compute the optimal path from the current position of the robot to these cells based on a deterministic variant of the value iteration (Eq. (3)). In the following, $c_{x,y}$ corresponds to the x-th cell in the direction of the x-axis and the y-th cell in direction of the y-axis of the two-dimensional occupancy grid map. In our approach, the cost for traversing a grid cell $c_{x,y}$ is proportional to its occupancy value $p(c_{x,y})$. The minimum cost path is computed using the following two steps:

1. **Initialization.** The grid cell that contains the robot location is initialized with 0, all others with ∞ .

$$T_{x,y} = \begin{cases} 0, & if\,(x,y)\,is\,the\,position\,of\,the\,robot \\ \infty, & otherwise \end{cases} \tag{2}$$

2. **Update Loop.** For all grid cells $C_{x,y}$ do:

$$T_{x,y} = \min \{T_{x+\Delta x,y+\Delta y} + \sqrt{\Delta x^2 + \Delta y^2}\,.P(C_{x+\Delta x,y+\Delta y}) \quad | \Delta x, \Delta y \in \{-1,0,1\} \wedge P(C_{x+\Delta x,y+\Delta y}) \in [0, occ_{\max}] \tag{3}$$

Where occ_{max} is the maximum occupancy probability value of a grid cell the robot is allowed to traverse. This technique updates the value of all grid cells by the value of their best neighbours, plus the cost of moving to this neighbour. Here, cost is equivalent to the probability $p(c_{x,y})$ that a grid cell $c_{x,y}$ is occupied times the distance to the cell. The update rule is repeated until convergence. Then each value $T_{x,y}$ corresponds to the *cumulative cost* of moving from the current position of the robot to $c_{x,y}$. The convergence of the algorithm is guaranteed as long as the cost for traversing a cell is not negative and the environment is bounded. Both criteria are fulfilled in our approach.

The resulting cost function T can also be used to efficiently derive the minimum cost path from the current location of the robot to arbitrary goal positions $c_{x,y}$. This can be done by steepest descent in T, starting at $c_{x,y.}$ As shown in Figure 2c the algorithm will calculate the shortest path to the unexplored cell. As soon as the robot reaches this cell, it will complete exploring the environment using the cost equation (1).

5 EXPERIMENT USING THE MINI-ROBOT KHEPERA

To test the implemented exploration algorithm with real robot, we use the Teleworkbench. We built the environment on one small field (1 meter x 1 meter). We use Lego bricks to form the environment. As the robot platform we use mini-robot Khepera II http://www.k-team.com. Its dimension is 5 cm in diameter with one on-board microcontroller. The robot's base module is equipped with eight infrared sensors. The maximum detection range using the Khepera II basic setting. Up to 7cm distance. One of the advantages of this robot is that it is extensible, which means that diverse auxiliary modules can be added on top of it. To allow longer runtime and wireless communication, we extend the robot with our extension module consisting of an additional, battery and a Bluetooth chip. With this module, the robot can operate up to 3 hours continuously.

5.1 Teleworkbench

The Teleworkbench is a teleoperated platform and test bed for managing experiments using mini-robots (Tanoto, 2005). The system is accessible via the Internet. Through the web-based user interface, local or remote users can schedule experiments and set programs to be downloaded to each individual robot. Via a Bluetooth module, robots can exchange messages to each other or to the Teleworkbench Server wirelessly. During experiments, the video server tracks the robots on the field to provide position and orientation of the robots. In parallel, this data will be stored locally and streamed simultaneously as live-video via the Internet.

For experiment analysis purpose, we developed a graphical analysis tool based on the MPEG-4 video standard (Tanoto, 2006). This tool allows us to visualize the internal and external behaviour of robots. With this tool, the recorded video of the experiment can be displayed together with some computer-generated objects representing important information, e.g. robot path, sensors' value, or exchanged messages. Moreover, users can interactively control the appearance of those objects during runtime. The Teleworkbench can use different types of mini-robots, such as Khepera II, as its robotic platform.

5.2 Algorithm Implementation

Based on the aforementioned algorithm, we develop the robot program in C language. The goal of the experiment is to explore an unknown bounded-environment of size 1 meter square. We divided the environment into 8 x 8 patches, each of which has a dimension of 0.125 x 0.125 m^2 as shown in Figure 3c. To detect obstacles or walls and their distance relative to the robot, we use robot's on-board infrared sensors. Thus, if an object is detected, the robot marks the patch with the object as occupied. Moreover, the robot gets its position by using odometry.

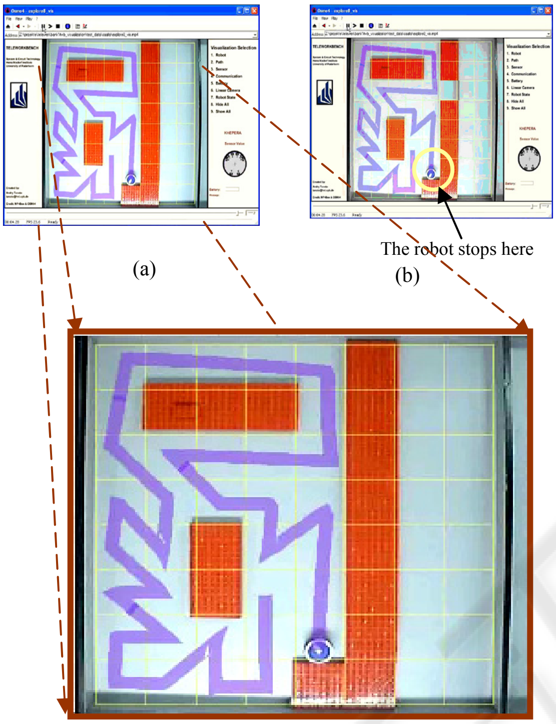
5.3 Experiment Setup and Execution

After code compilation, we download the program remotely via the Teleworkbench web-based user interface. During testing, we ran several experiments with different parameters, such as varying the threshold for the infrared sensors, etc. this is needed due to hardware unideality that is not taken into account during simulation. We did each experiment as follows: select a robot, download the program, turn on the webcam in record mode, free the robot after the experiment is over, and save the video data and the log files to be used for analysis. After each experiment, we ran the post experiment analysis tool which will generate an MPEG-4 video with the video of the experiment and the robot path as well as some colour tiles representing the patches.

5.4 Experimental Result

Experiments had been executed with the same environment setting and initial position. The result shows that by using the LNA the robot could explore all the free patches in the environment as shown in Figure 3a. But if the environment appears as shown in Figure 3b, the robot stops when it finds that all its neighbours are either explored or wall. But when applying the MLNA the robot could successfully explore all the free patches in the environment. Moreover, it could detect obstacles and walls robustly by using only its on-board infrared sensors as shown in right image in Figure 4.

The MPEG-4 video played-back on OSMO4 video player shows the path of the robot during the experiment. If needed and available, other information, such as sensors, internal state, etc, can also be displayed.



(c)

Figure 3: (a) Snapshots of the video visualizing the exploration experiment using LNA. (b) The trapped robot problem in LNA. (c) Zooming on the environment

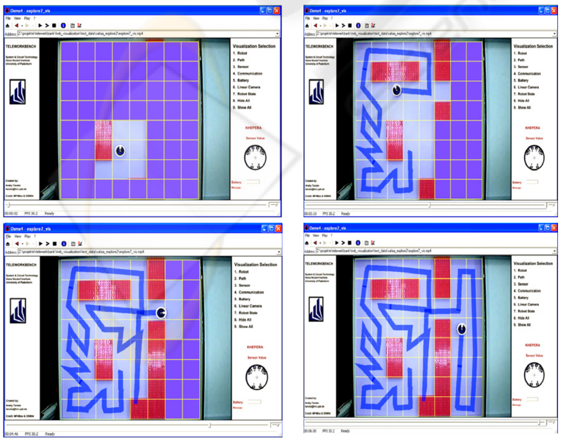


Figure 4: Snapshots of the video visualizing a step by step exploration experiment of an unknown environment using the MLNA.

However, we can see that the robot path deviates when it travelled from one patch to the other, as shown in Figure 3 and Figure 4. This is mainly due to the error generated by odometry. As a result, in some occasions the robot collided with obstacles or walls during its movement. Another interesting point from the experiment is that there is one occasion in which the robot had to select one of two patches with the same minimum cost (top-left image in Figure 4). By using the distance calculation (sec.4.1), the robot chose the patch exactly below it because of its shorter relative distance to the current robot position compared to the one of other cells.

6 CONCLUSIONS

In this work the modified local navigation strategy for static unknown environment exploration has been implemented and tested using the mini-robot Khepera running on the Teleworkbench. Experiments presented in this paper demonstrate that the modified exploration algorithm is able to cover successfully the whole unknown environment and overcome the draw back in LNA. Moreover, by taking into consideration the distance of neighbouring cells to the current robot position, the robot always select the cells with minimum distance, thus less energy and time. We notice also the weakness of odometry to provide the robot's position. To improve it, we plan to get more robust position information from the Teleworkbench. Moreover, varying environment setups and initial locations are necessary to prove the robustness of the algorithm.

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