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Cooperative Indoor Navigation using Environment-Embedded Assistance Devices

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1. Introduction

The research in environmental robotics, ubiquitous robotics, and network robots aim to create intelligent environments for providing various services by gathering, managing, and supplying information via distributed communication, sensing, and actuation. Various applications of such robotic systems have been proposed and studied, e.g. life support (Sato *et al.*, 1996), environmental monitoring and information management (Parker *et al.*, 2003; Low, 2004; Tang, 2004), task assignment (Batalin & Sukhtame, 2003), and rescue operation (Kurabayashi *et al.*, 2001; Tadokoro *et al.*, 2003; Miyama *et al.*, 2003). These applications employ various navigation methods addressed in numerous publications (Borenstein *et al.*, 1996; Arai *et al.*, 1996b; Li *et al.*, 2003; Parker *et al.*, 2003; Nakamura *et al.*; 2003).

This chapter introduces a cooperative navigation method for multiple mobile robots operating in indoor environments, as an example of our research work in intelligent environmental robotic systems. The method relies on the information management about the environment, namely, static global information and local information. The former is represented by a topological map (Mataric, 1992) that displays the positional relation from any starting point to any goal point and is relevant for planning a route. The latter contains a map of the local environment and the traffic information for dynamic navigation.

The proposed navigation method makes use of an Information Assistant (IA) – a communication device embedded into the environment. The IA updates and manages information about the local environment and communicates with the robots. The navigation also relies on an Optical Pointer (OP) to guide robots at intersections by means of projecting a laser light onto the ground. The OP communicates with the robot via the IA, when indicating target positions to the robot. The mobile robot detects a laser beacon on the ground by means of image processing and moves towards the beacon. When the robot reaches the proximity of the beacon, the next sub-goal is indicated, and the laser beacons lead the robot along the route. The IA and OP devices assist the robot to navigate in the environment, which can be unknown to the robot.

In contrast with other navigation methods, where the robot attempts to process all the information available about the environment, e.g. simultaneous localization and mapping (Smith *et al.*, 1990; Choset & Nagatani, 2001) or an improved topological map (Tomono &

Yuta, 2001), the IA and OP devices allow us to share the environmental information among the robots and obtain more flexibility in navigation and information management.
Section 2 discusses the information management for navigation with the use of the environment-embedded IA and OP devices. The cooperative navigation is presented in section 3. Section 4 describes our experiments on robot navigation. The conclusions are given in section 5.

2. Information Management for Navigation

This section addresses the information management for robot navigation in a structured indoor environment, where passages and intersections are constrained by walls. The global environmental information is used for planning a coarse route for the robot. The local information at intersections serves for accurate navigation along the planned route.
The global information is represented by a topological map that contains the general relational data about the present location, goal, and intermediate locations. For example, the environment in Fig. 1 is represented by a topological map in Fig. 2 with the use of a graphic expression. In this map, the focus is on the topology of environment. The graphic search is used to plan a coarse route on the basis of the global map known in advance.

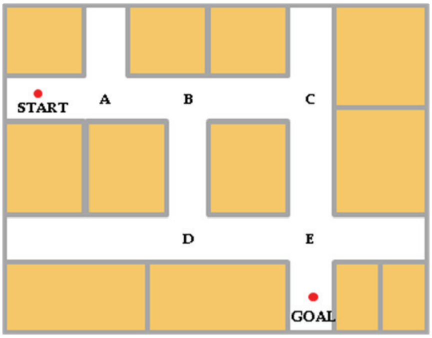


Figure 1. Example of an indoor environment: intersections are denoted by A, B, C, D, E

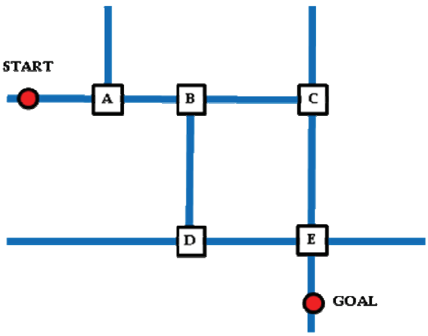


Figure 2. Topological map with passages and intersections

The processing of local information by the robot allows it to obtain a feasible path along the planned general route. While the robot can easily move in a passage along the wall, it cannot easily navigate at an intersection because the layout of any intersection is not uniform and the path cannot be supplied in advance. The traffic control is also needed at intersections to ensure collision-free motion. The information assistance at intersections facilitates the robot navigation. The local information is usually specific for each intersection and it depends on the actual state of the local environment. By means of embedding the assistance devices into the environment, the local information can be efficiently managed and made available to the robots for planning their feasible local paths.

2.1 Environment-Embedded Devices: Information Assistant and Optical Pointer

The Information Assistant (IA) is a radio device with the following functions: management of local information, robot communication, and control of interconnected devices such as sensors. The IAs are embedded into the environment at intersections and other areas to provide the relevant local information to mobile robots. The robot can retrieve or write information from/to an IA. This enables the information sharing among robots, e.g. the data written by a robot to the IA becomes available to other robots. The robot requests the local information from the nearest IA and, subsequently, plans its local path.
However, the local information is often insufficient for accurate navigation. Figure 3 shows an example of an erroneous arrival point after the robot passed the intersection because dead-reckoning was used. The following issues can also cause the navigation problems:

1. There are time variations in receiving the radio signals from the IA that results in an uncertain start position of the robot at intersections.
2. There are measurement errors of an angle between the robot's direction of motion and the wall during maneuvering.
3. The navigation errors can occur while the robot moves through intersections.
4. The presence of obstacles increases the risk of positional uncertainty, especially in the proximity of the start position at intersections.

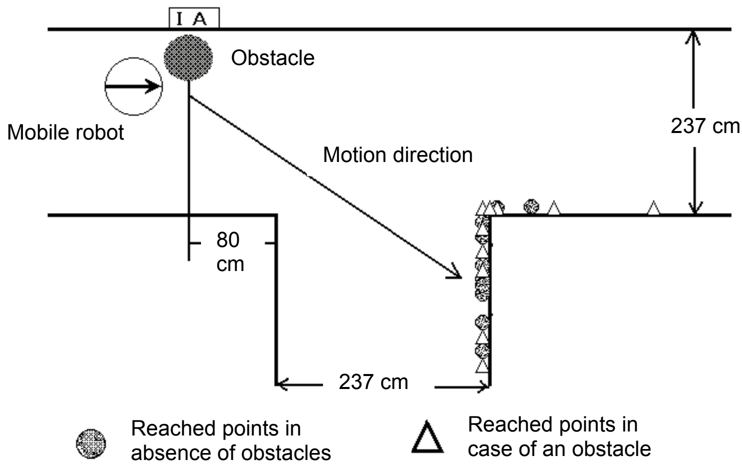


Figure 3. Example of robot navigation based solely on IA

The Optical Pointer shows a target position to the robot by means of projecting a laser light onto the ground (Paromtchik & Asama, 2001). The robot detects the laser beacon by means of image processing and moves toward it. When the robot reaches the proximity of the beacon, the OP indicates the next sub-goal along the route at intersections. Fig. 4 illustrates the concept of using IA and OP for robot navigation.

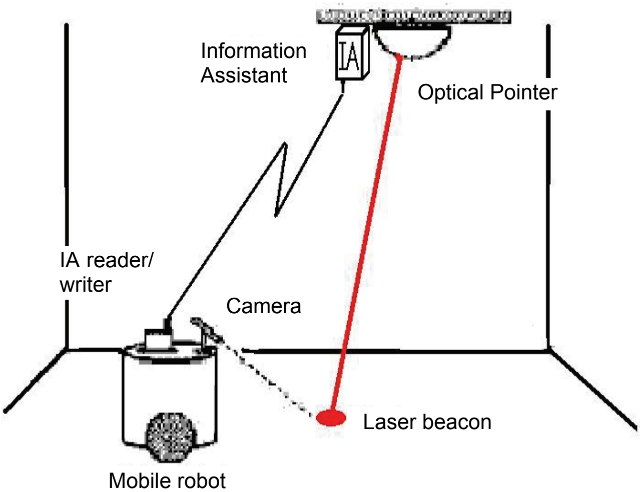


Figure 4. Concept of using the IA and OP devices for robot navigation

2.2 Navigation Algorithm

The navigation algorithm relies on the IA and OP devices embedded into the environment. The algorithm consists of the following steps:

(1) Provide a global topological map and the robot's start location.
(2) An operator specifies a goal, which is transmitted to the robot via a wireless LAN.
(3) Based on the start and goal locations, the robot plans a coarse route by means of the graphic search in the topological map.
(4) The robot moves along the planned route and monitors the local environment by means of infrared sensors to avoid collisions with obstacles.
(5) When the robot arrives at an intersection, it detects the IA's radio signal and communicates with the IA by requesting guidance at the intersection. Fig. 5 shows the communication process between the robot and the IA.
(6) The IA receives a start and goal positions from the robot, and transmits the information about the feasible local path.
(7) The OP shows a laser beacon as a sub-goal for the robot.
(8) The robot processes images to detect the laser beacon and moves toward it. The IA and OP devices guide the robot by means of the laser beacons.
(9) When the robot has entered the next passage, it sends a message to the IA to confirm its successful passing through the intersection.
(10) The robot continues its motion along a passage.
(11) When the robot reaches another intersection, the optical guidance is performed again.

Finally, when the robot receives the goal information from the IA, this signifies that the robot has completed the motion task successfully. If two or more robots arrive at an intersection, the priority is given to the robot that first requested guidance from the IA. Other robots receive a busy signal from the IA and wait in their current positions until the guidance service becomes available for them. Thus, the same navigation scheme can be used for multiple robots in the same local environment.

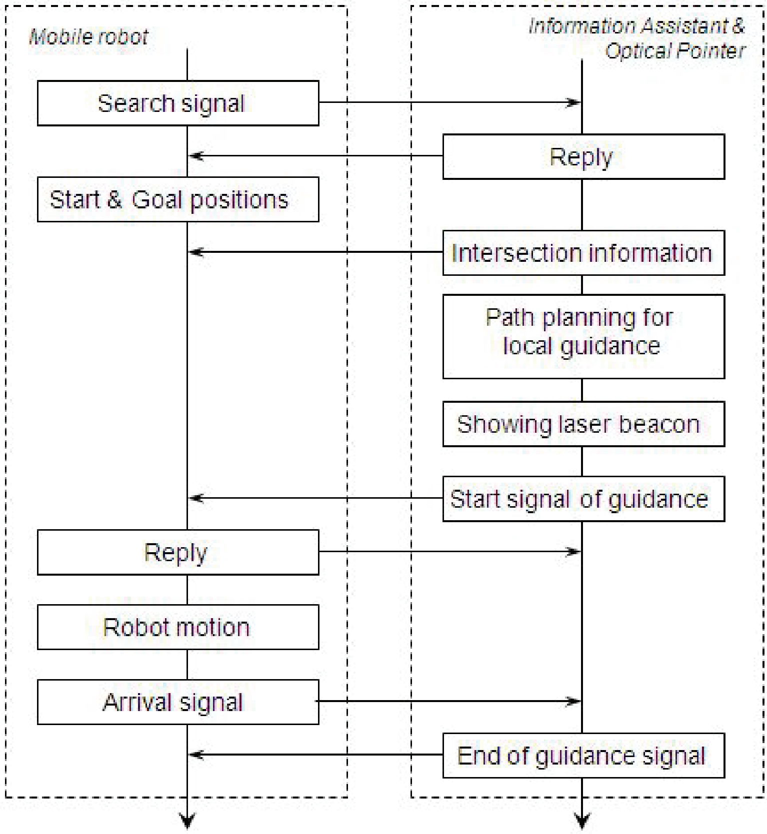


Figure 5. Communication between the mobile robot and the IA and OP devices

3. Navigation System

In order to realize the proposed navigation scheme, we have developed an experimental prototype. This section describes our experimental setup with the omni-directional mobile robot, information assistant and optical pointer.

3.1 Omni-Directional Mobile Robot

The robot is shown in Fig. 6. It is equipped with a holonomic omni-directional wheeled platform with its actuators, sensors, on-board control system and electric batteries (Asama *et al.*, 1995). Its infrared sensor system LOCISS (Locally Communicable Infrared Sensory System) is capable to distinguish a robot and an obstacle in an environment with multiple robots (Arai *et al.*, 1996a). LOCISS allows the robot to detect and avoid obstacles, follow a wall, and it also serves for local communication between robots.

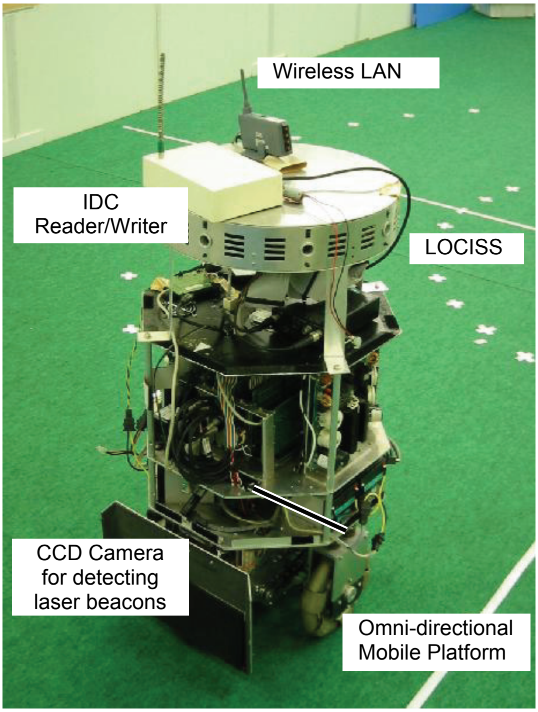


Figure 6. Mobile robot ZEN

3.2 Information Assistant and Optical Pointer

The IA device is based on the Intelligent Data Carrier (IDC) (Arai *et al.*, 1996b) and an IDC Reader/Writer. The 4th version of IDC is shown in Fig. 7. The IDC is a device with a radio communication unit, a CPU, a memory, and an electric battery. The robot communicates with the IDC through the IDC Reader/Writer.

The OP device consists of a laser pointer mounted onto a pan-tilt mechanism with two step motors. The pan-tilt mechanism directs the laser beam onto the desired positions on the ground. The Fig. 8 shows an OP which is installed at the ceiling.

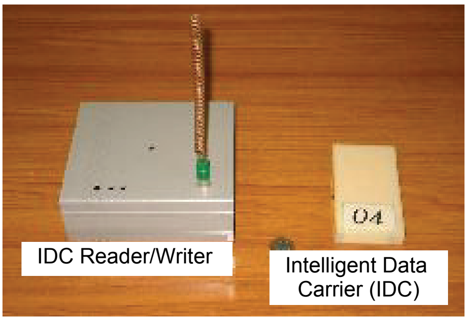


Figure 7. The IA device is based on IDC Reader/Writer and Intelligent Data Carrier

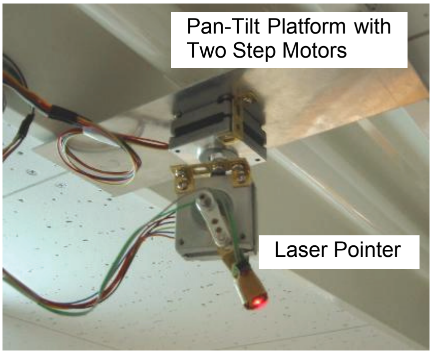


Figure 8. The OP device is mounted onto a pan-tilt mechanism at the ceiling

4. Experiments

The experiments are performed in an indoor environment of RIKEN. The floor map is shown in Fig. 9. The robot's task is to move from its start location to a goal which is set by a human operator. The IA and OP devices are placed at the intersections in the environment.

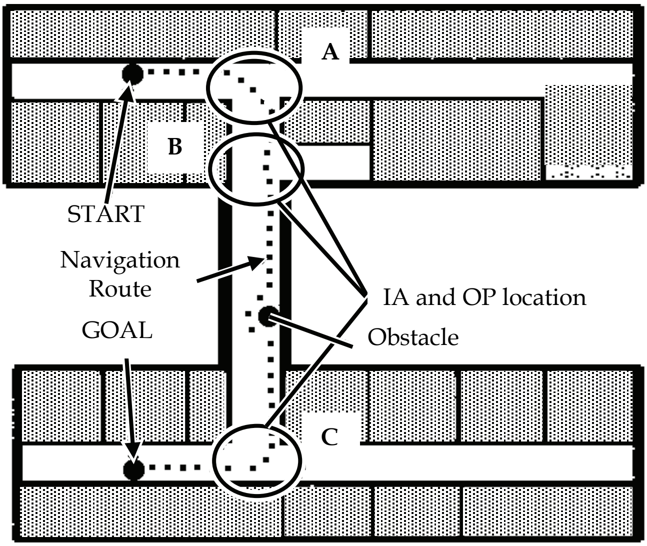


Figure 9. Floor map of our experimental environment

They contain information about their own positions and environmental conditions at the intersection. The circles and letters A, B, C in Fig. 9 denote intersections, where the IA and OP devices are placed, and the circles also indicate the communication range for local navigation. Given the start position and goal destination, the robot planned a coarse route as: START – A – B – C – GOAL by means of a graphic search on the topological map. The obstacle detection and avoidance was provided by LOCISS. After moving along a passage, the robot approached an intersection A, where it detected the IA and requested guidance through the intersection. The OP indicated the feasible path by means of laser beacons, as shown in Fig.10 and Fig. 11. The motion from START to GOAL is depicted by a dotted line in Fig. 9.

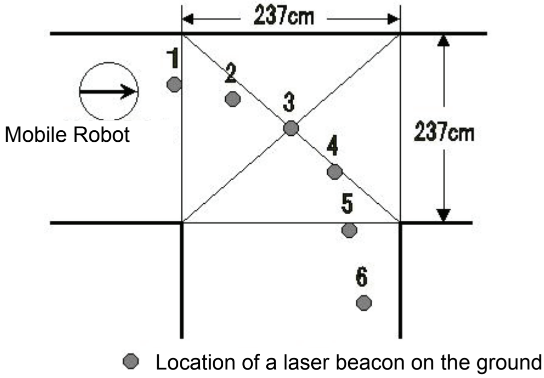


Figure 10. Location of laser beacons at intersection A, one laser beacon is shown at a time

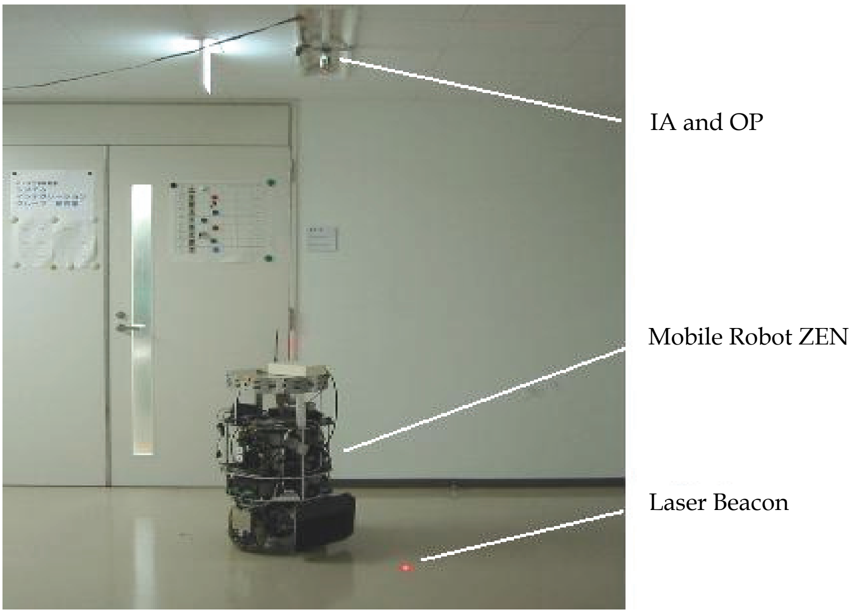
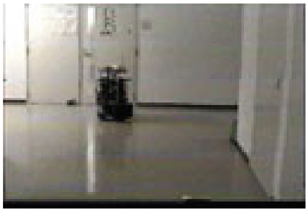
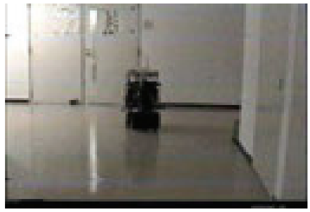
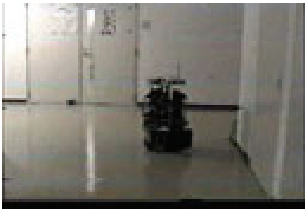


Figure 11. Navigation by means of IA and OP at an intersection

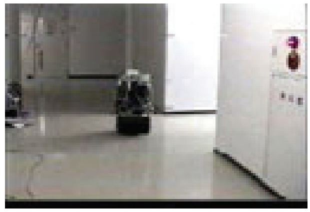

(a) The robot moves from its START location along the wall

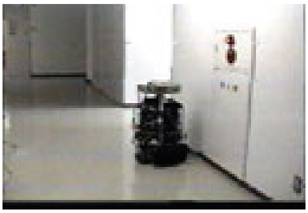

(b) The robot communicates with the IA and OP at intersection A

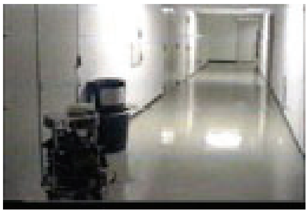

(c) The IA and OP guide the robot at intersection A

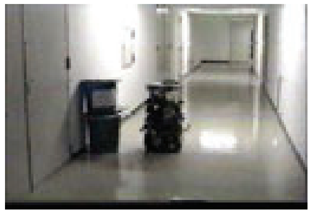

(d) The robot enters the passage and moves along the wall

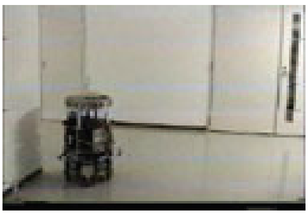

(e) The robot communicates with the IA and OP at intersection B

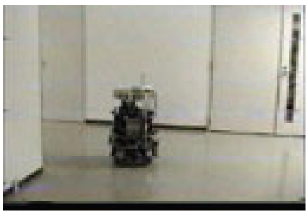

(f) The robot is guided by the IA and OP at intersection B


(g) The robot moves along the wall after the guidance


(h) The robot detects an obstacle on its route by processing range data


(i) The collision avoidance is performed with the use of LOCISS


(j) The robot communicates with the IA and OP at intersection C


(k) The robot is guided by the IA and OP at intersection C

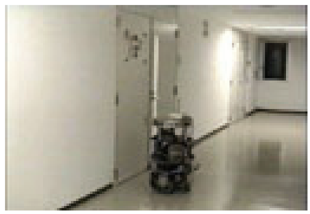

(l) The robot finally arrives at its GOAL destination

Figure 12. Robot navigation experiment with the IA and OP devices

5. Conclusion

This chapter introduced a cooperative navigation strategy for mobile robots operating in indoor environments with the embedded Information Assistant and Optical Pointer devices, as an application of an intelligent environmental robotic system. In order to provide a more flexible navigation, the management of environmental information was considered. The static global information supplies topological details such as the positional relation of any starting point to any goal point in order to create an approximate route. The dynamic local information includes a local map, obstacles and traffic information for accurate navigation. We proposed the information management and navigation algorithm based on the IA and OP devices embedded into the environment. The experimental example of navigation was described. The robot was initially provided with a coarse route to the goal, and the IA devices managed the environmental information in real-time locally. The OP device was used for guidance at intersections, and communication with mobile robots was performed through the IA device. The OP indicated target positions by means of a laser light projected from a laser pointer onto the ground. The mobile robot detected the laser beacons and followed them to reach its goal destination. The experiments have proved the feasibility of the proposed method.

6. Acknowledgment

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