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An Intelligent Navigation Method for Service Robots in the Smart Environment

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Abstract: Autonomous navigation is one of primitive functionalities which service robots should have; nevertheless, the navigation problem for a service robot still has many difficulties because the real environment where service robots should works is so complex and dynamical. This paper proposes a framework of intelligent navigation for service robots based on a semantic map of the smart environment. In the smart environment, the robot can receive his position information from location sensors by sensor networks, and it can eliminate the accumulated localization errors. So the robot can accomplish confidential localization in the dynamic and complex environment. With the topological information in the semantic map, path planning problem can be simple even in the wide and complex spaces, and topological path from semantic map can be divided into several sub goals. Robust navigation can be accomplished by moving towards these sub goals with reactive navigation algorithm which has robust characteristics in the dynamic environments. Our approaches have ascertained the good performance on the localization and the navigation, and the feasibility of these methods could be confirmed with the result of experiments in the real environment.

Keywords: Navigation, Mobile Robot, Semantic Map, Smart Environment

1. INTRODUCTION

Recently, the importance of intelligent navigation for mobile robots has been increasingly recognized with the growing interest in service robots. Service robots should recognize surrounding environments with their sensors, and take immediate steps against unexpected situations automatically[1]. A considerable amount of research has been conducted to make the mobile robot perform the navigation intelligently. However, in spite of many research results on autonomous navigation, it is still remained as difficult problem that a mobile robot navigates confidently in real environments.

This paper considers a new intelligent navigation method for service robots with smart environment technologies. Fundamental functionalities for intelligent navigation are classified into localization, mapping, path planning and control subject. Since these functionalities influence each other, each performance is highly dependent upon others. Therefore, to achieve intelligent navigation dependably, a system architecture which can operates these functionalities in cooperation with each other is considered to be an important subject. So we proposed a system framework for intelligent navigation as fig. 1. This scheme contains semantic map, wide area localization and navigation manager components. Our approaches are based on the smart environment in which the robot can obtain useful information about intelligent navigation by interacting with the smart environment components.

In this work, a semantic map structure which contains environment's topology, metric, semantic information is proposed, and wide area localization and intelligent navigation algorithm based on the semantic map are developed. This paper is focused on our noble framework for service robots to accomplish intelligent navigation using the semantic map information. Though our approach calls for some infrastructure requirements, it can be expected that service robots will be provided more reliable navigation abilities by smart environment.

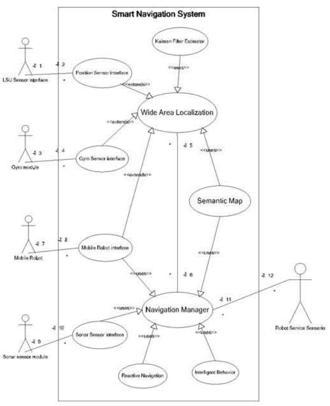

Fig. 1 The system framework for intelligent navigation

2. SMART ENVIRONMENT BASED NAVIGATION SCHEME

2.1 Overview

Autonomous navigation systems for mobile robot are generally composed of '*map building*', '*localization*' and '*path planning*' algorithms[1]. These algorithms are dependent on others respectively and have to be operated with highly linkage to accomplish autonomous navigation. However, each algorithm contains many uncertainties and disturbances at real applications, because real environments where service robots should work are so dynamical, complex and wide area which has many similar patterns; therefore whole uncertainty of total navigation system could be more magnified, and realization of autonomous navigation in the real environment seems to be a difficult problem.

In the smart environment, localization and navigation problems could be more reliable. Because location sensors which are installed in the environment tell position information to the robot through sensor networks and environment map which contains topology structure and semantic information can be downloaded from the smart environment operating

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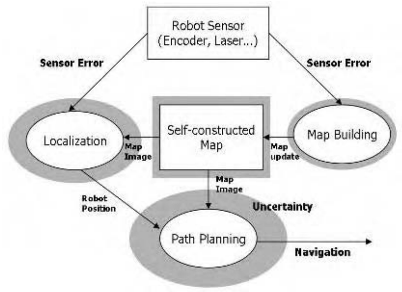
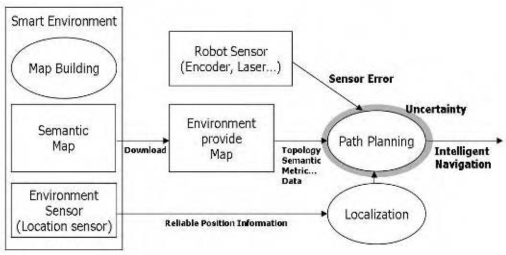
server, uncertainties in the map building, localization and path planning problems can be reduced and the robot can accomplish dependable navigation. Fig. 2 shows comparison of differences between existing methods and smart environment based method.



(a) A typical scheme for robot navigation



(b) Our navigation scheme in the smart environment

Fig.2 Comparison of navigation schemes

2.2 Map building (in Smart Environments)

In the existing popular navigation methodologies, such as SLAM, map building is a process that a robot comprehends surrounding environments with his own sensors[2][3]. It is essential but exhausting and difficult task to robots for navigating in the unknown space. However, in smart environments, previously built maps are saved in the environment server system and it can be downloaded using network when the robot requests map information. Therefore, map building process which is exhausting and difficult is not necessary in our smart environment based navigation methodology.

Generally, maps are represented as ‘occupied’, ‘empty’ in the existing method. However, in this research, we proposed a map structure which can contains environment’s topology, metric, semantic information, and it enables wide area localization and intelligent navigation in the smart environment. In addition, our map can be represented with XML expressions, and it enables sharing of the map with standardization on map structures.

2.3 Localization (in Smart Environments)

In order to move toward goal place or follow a path, the robot has to know where it is; this is referred to as localization. In Most of localization methods, the robot position is estimated by comparing surrounding sensor data with previously composed map data[4]. However, it may contain many uncertainties and errors, because real environments are so dynamical, complex and wide area which has many similar patterns. In our approach, the robot receives his position data from location sensors which are installed on environments through wireless communications. For this purpose, we have developed a location sensor system which can detect absolute position of the robot. Fig. 3 shows the conceptual diagram of our location sensor system. The location sensor consists of IR projector that requires position information and PSD module that determines the position of the IR projector; those two modules are connected by wireless sensor network, such as Bluetooth or ZigBee[5]. In addition, with the semantic map information the robot can select proper location sensor among multiple sensors at the current position, and connect to the proper location sensor automatically; therefore, by out method, the robot can not lose his position even though it navigates in more wide areas.

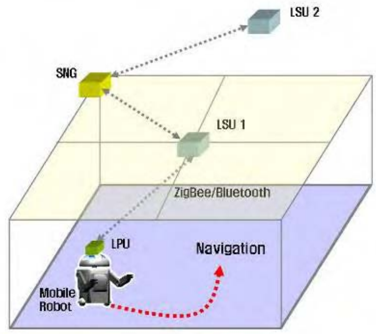


Fig. 3 Conceptual diagram for location sensor system

2.4 Path planning (in Smart Environments)

Path planning is tightly concerned with the map description paradigm. There exist two major paradigms for mobile robot navigation: *Metric* and *topological*. Approaches in the metric paradigm use fine-grained, metric descriptions of a robot’s environment. On other hand, approaches in the topological paradigm use coarse, graph-like descriptions of environments. It is known that path planning problem using topological map is more simple and clear than metric map[6][7]. Since our proposed map scheme is consisted based on topological paradigm, path planning problem can be simple even in the wide and complex spaces by topological information in the semantic map. Furthermore, our path planning method can add metric and semantic information to topological path planning result; it enables the robot navigates more intelligently in real environments.

3. SEMANTIC MAP FOR SMART ENVIRONMENTS

3.1 Structures of semantic map

As mentioned earlier, we proposed a new semantic map structure for smart environments based on the topological paradigm. In our semantic map structures, world space is represented as connections of cell units, and a cell is expression of a distinctive place. As shown in Fig. 4, proposed map structure represents a cell as a rectangle space, and supposes that cell is consisted of *connection points* which represent connection with other cells, *location sensors* and *fixed objects* which are useful as landmarks.

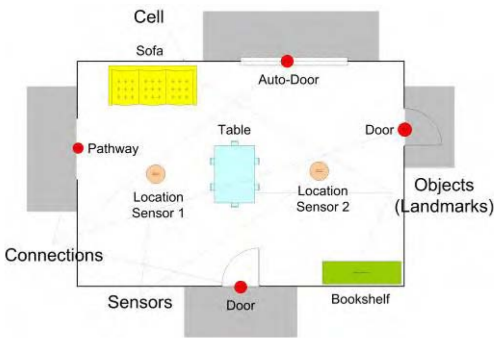


Fig. 4 Representation of a cell space

Following above representation on cell spaces, we divided a cell into 5 sections: *Semantic, Metric, Connections, Sensors, Object* layer. *Semantic* layer includes semantic information such as type, name. Referring to semantic layer data, robot knows where he is in and what kind of place is current position. Semantic layer enables semantic level path planning; i.e. "What is the path which can get the place *Office #101*?"

Metric layer includes metric information about each cell. Since we modeled a cell as rectangle space, only position (*x, y*) and size (*width, height*) data is required for representing that place. Using the metric layer information, position data can be converted to cell data, and cell data to position data. *Connection* layer includes information on connection points which are linked to neighbor cells, and it represents topological structures of the whole environment.

Sensors layer includes location sensor information to select and connect automatically to the proper location sensor among multiple sensors. For this functionality, sensors layer contains data such as installed position, direction and network address. *Object* layer includes information on fixed object which can be utilized as landmark; it contains place position data (*x, y, q*) and RFID code data (128 bit).

With these 5 layer information, the robot will accomplish tasks of localization and path planning more reliably and simply. Fig. 5 shows hierarchical structure of our semantic map layer for an example map.

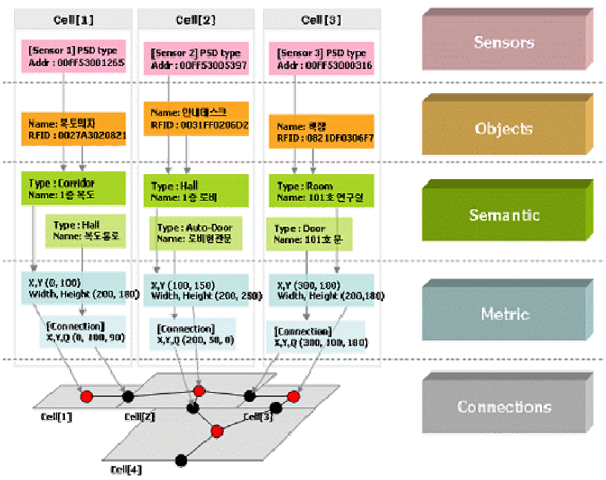
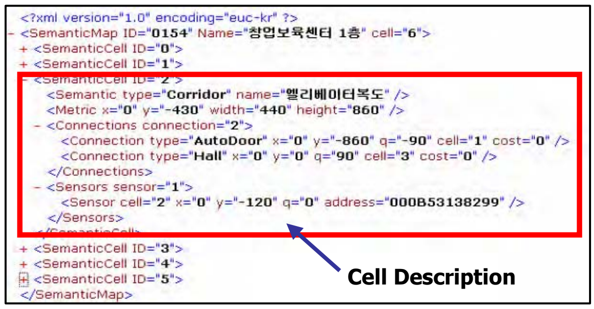


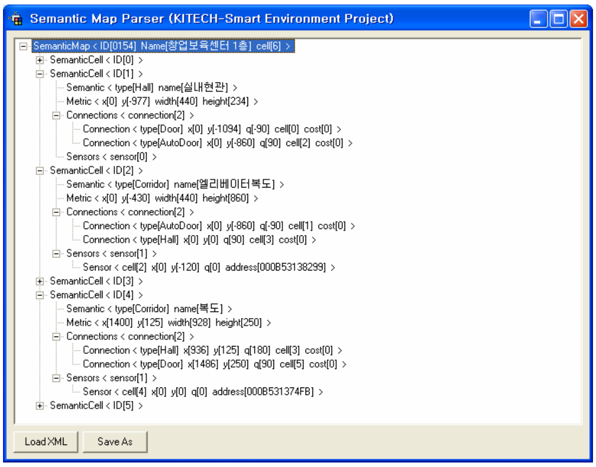
Fig. 5 Hierarchical structure of semantic map layer

3.2 Representing semantic map with XML

As shown in previous chapter, our semantic map designed with 5 layers. With simplicity and conciseness of our map structures, map can be represented by XML expressions. Representing map with XML has some merits on sharing and flexibility. An XML file contains semantic map information can be downloaded through internet from the server to any robot who want to know information on a certain environment; therefore, a robot who has no pre-knowledge on current environment can comprehend the surrounding workspace by only connecting to the server and downloading the XML map file. In addition, XML expressions provide flexibility on modification in map structures and addition/removal of data fields. Fig. 6 shows our XML expressions on a cell and screen image of XML map parser software loading an example semantic map.



(a) XML expressions on a cell



(b) Screen image of XML map parser software

Fig. 6 Semantic map expressed by XML

4. LOCALIZATION AND PATH PLANNING IN THE SMART ENVIRONMENT

4.1 Smart environment based localization

In the smart environment on our configurations, location sensors have detecting limit, and it is known as about 5m diameter. Since the robot moves continuously with performing autonomous navigation, it is necessary that functionality for managing connections with location sensors and selecting the proper sensor at current position[8]. For this functionality, we add *Sensors* layer to our map structures; it provides sensor install and connecting information.

For selecting the proper sensor, a candidate set which contains whole location sensors in current cell and its neighbor cells is composed. The proper sensor is selected by Eq. (1); where $S = \{s_1, s_2, s_3 \dots s_N\}$ is candidate set for selecting proper sensor, X_S and X_R presents sensor position and robot position respectively.

$$s_{opt} = \min\{\, \| X_S(i) - X_R \| \,, s_i \in S,\ i = 1, \dots, N \} \quad (1)$$

Fig. 7 shows an example of selecting a proper sensor. In this condition, cell of current robot position is C3 and its neighbor cells are C2, C4, C5; therefore S is set of location sensors in C2, C3, C4, C5 cells, and candidates set is $S = \{s_1, s_2, s_3\}$. In selecting proper sensor, search space could be remarkably reduced by cell layer information, particular in large area, and install position data in sensors layer are used in computing distance between the robot and candidate sensors. Selected sensor is compared with current location sensor; if two sensors are different, the robot must try to connect with new selected sensor using the network address information in sensors layer of semantic map.

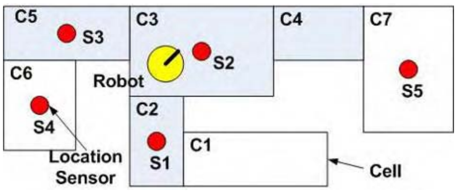


Fig. 7 An example of selecting a proper location sensor

4.2 Smart environment based path planning

Since our map structure is based on topological map, path planning is start with getting topological path using graph searching method. However in our method, various information such as metric and semantic data can be added to topological path (we named it '*semantic path*'), because proposed map is consist of hierarchical structure; furthermore, various type of requesting path is possible[9]. As shown in Fig. 8, layers are consisted of (*Semantic*, *Objects*)-(*Metric*)-(*Connections*). Although final path planning is performed at connections layer, path planning requests by whole layer level are possible; for example, metric level - PathTo(x, y, q), semantic level - PathTo("Room #101") and object level - PathTo("00FF312310FC") are all enabled.

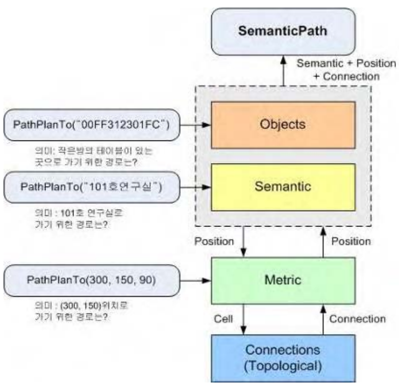
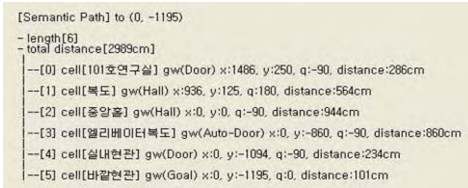
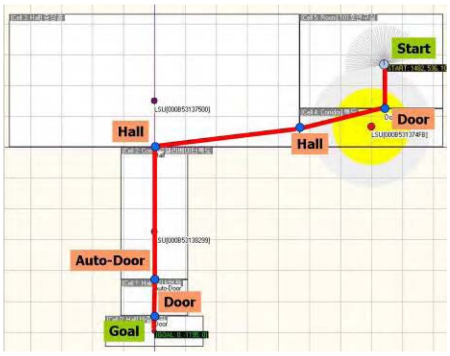


Fig. 8 Path planning process using semantic map of the smart environment

Fig. 9 shows an example of path planning using semantic map. As shown in (a), presented semantic path result contains semantic information, such as cell type, name and connection point type, and metric information, such as position of connection points, distances between each point. Therefore, by referring semantic path information, the robot can comprehend that how far each connection point is and what kind of cell and points the robot have to pass through. (b) shows graphical representation of derived semantic path on the real map image.



(a) Semantic path derived from semantic map



(b) Graphical representation of semantic path

Fig. 9 An example of path planning using semantic map

4.3 Navigation manager

The navigation manager executes proper behavior using the semantic map path information. It manages reactive navigation behavior and other basic behaviors, and expire a proper behavior at suitable situation. For example, if the service robot moves into a room, the robot should acts door-open behavior when it arrived at front of the door of room. Navigation manager executes these operations which concerned with the intelligent navigation. Fig. 10 shows an example process of the navigation manager referring a certain semantic path.

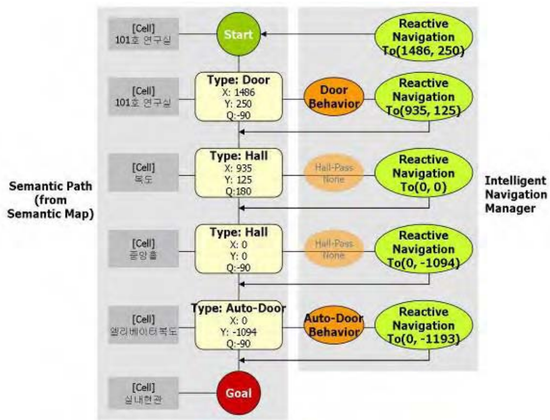


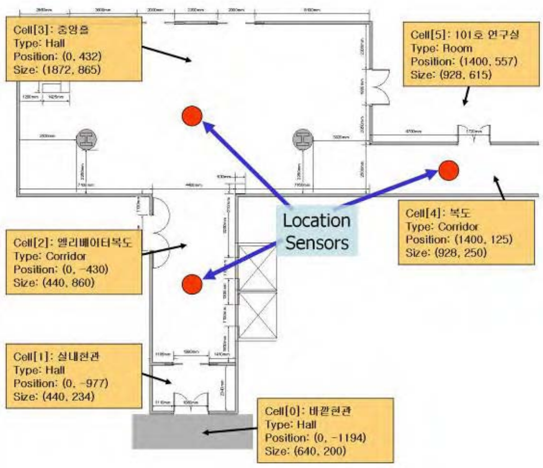
Fig. 10 Navigation manager process for a semantic path

5. EXPERIMENTS IN THE REAL ENVIRONMENT

5.1 Experimental environment configurations

To verify the effectiveness and propriety of our navigation approaches in real environments, our office building is selected as experimental space. We installed 3 location sensors on the proper position and measured the information for drawing up the semantic map. Fig. 11 shows real photos of our experimental space (a) and the sketch of it with installed location sensors, measured map data (b).

(a) Real photos of experimental space



(b) Drawing of experimental space and configurations

Fig. 11 Experimental environments

Fig. 12 shows our test robot platform–'*SmaRob*' and screen image of implemented our robot operating software. *SmaRob* has 7 sonar sensors on the front side for detecting dynamic obstacles and 1 IR projector on the topside to get position data from location sensors.

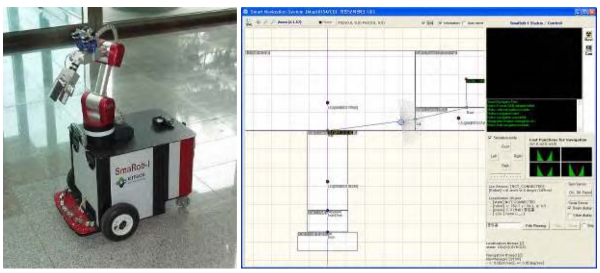


Fig. 12 Test robot platform and operating software

5.2 Navigation test result

With these experiment configurations, test navigation was performed in the real environment. We designated a certain position in front of door of 'office #101' as start position, and designated entry hall as goal position. Fig. 13 shows overall processes that the robot autonomously navigates to designated goal position.

(a) presents the result of path planning. To arrive at entry hall (goal position) the robot has to pass through 3 connection points-2 hallways and 1 auto-door. When the robot pass through hallways, no specific behavior is necessary, because hallway is just open space. However, the robot must check state of the connection points when pass through auto-door.

(b), (e), (i) shows that the robot passes through each connection point-'*hall, hall, auto-door*'. (d), (g) shows that the robot connects to new location sensor according to movement of the robot.

In (c) and (f), the robot shows reactive behavior-'*obstacle avoidance*', when detects a moving obstacle (walking man) and a fixed obstacle (standing man).

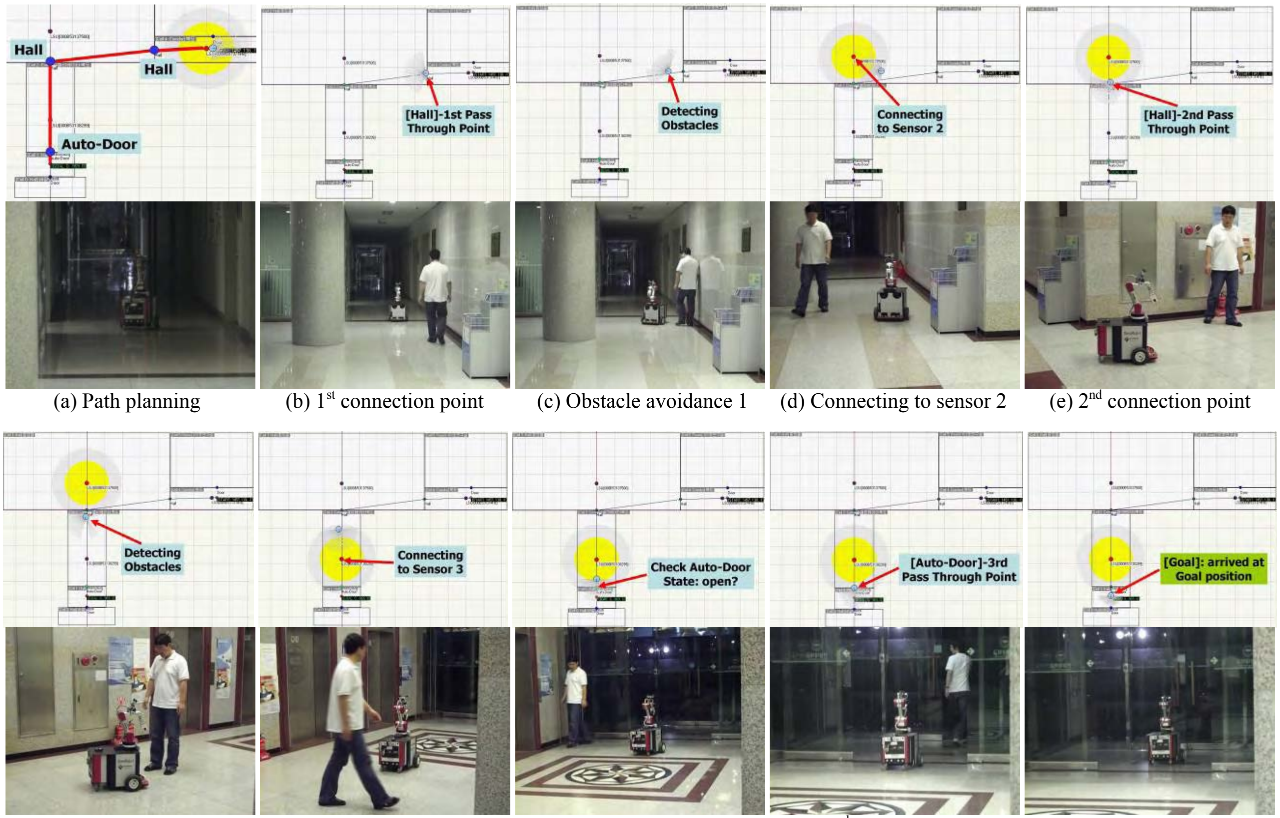
(h) shows that the robot checks state of door with sonar sensors when he arrived at auto-door connection point. Finally, the robot arrived at goal position in (j).

As shown in Fig. 13, this navigation test presents mixed result of our proposed methodologies. (a) shows proposed *semantic map based path planning* result, and it contains metric and semantic information as well as topological path information. (d), (g) shows the functionality of proposed *wide area localization* using semantic map information. (b), (e), (i), (h) shows the operation of *navigation manager* that enables intelligent navigation using semantic path information, and besides (c) and (f) shows the robust characteristics of the reactive navigation behavior.

6. CONCLUSION

This paper has presented the framework for intelligent navigation in the smart environment. For accomplishing this mission, we designed a semantic map structure which contains various kind of information for utilizing intelligent navigation. With this map structures, we proposed methods for wide area localization, path planning and navigation manager functionalities. These approaches are implemented on the real environment and mobile robot platform, and experiments are performed to verify the effectiveness and propriety of proposed navigation methods in real environments. Our approaches have ascertained the good performance on the localization and the navigation, and the feasibility of these methods could be confirmed with the result of simulation and experiments.

Though our approach calls for some infrastructure requirements, it can be expected that service robots will be provided more reliable navigation abilities by smart environment. It is desirable, as the next research, to make navigation functionality more intelligent with developing variety behaviors necessary for intelligent navigation, such as behavior of opening door and behavior of getting into/out an elevator.



(a) Path planning (b) 1^{st} connection point (c) Obstacle avoidance 1 (d) Connecting to sensor 2 (e) 2^{nd} connection point

(f) Obstacle avoidance 2 (g) Connecting to sensor 3 (h) Check auto-door state (i) 3^{rd} connection point (j) Arrived at Goal

Fig. 13 Overall processes that the robot navigates to designated goal position

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