研 究 解 説

Physical Agent in Intelligent Space

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1. Introduction

In last several years, the proliferation of networks and the integration of vision systems in the networks have led to a new paradigm of the networked vision systems. They are no longer seen as an isolated vision system for a specific task but as the sensor component of the intelligent infrastructure of the space, they look at. Such an intelligent space is able to perceive what is happening in it, build a model of itself, communicate with its inhabitants and interact with events. The capability of such a space, to act as a highly context-sensitive user interface and to respond to certain events in it (e.g. accidents, intruders), promises a wide range of application scenarios. Examples are intelligent hospital rooms, offices, factory floors, or homes for the aged.

Mobile robotics are a research field in which much research has been conducted in. In past decades, most of the works have focused on giving the mobile systems autonomy, and thus they were trying to make isolated intelligent system. For achieving this kind of system, several techniques are needed such as localization, path planning, sensor fusion, obstacle avoidance etc. However, the most important thing in constructing an autonomous mobile system is design of architecture. Performance of mobile systems depends mostly on the architecture even though they use same subdivision modules.

In this paper, we propose new system integration. By combining the mobile robots and the intelligent space, we are able to get many good features, which could not be obtained before. This combination results in a proposal for modifying the mobile robot research flow with the inclusion of additional step before achieving a fully autonomous intelligent robot. The new flow is expected to accelerate the mobile robotics research. As shown in Fig. 1, most of researchers are trying to make a full autonomous mobile robot. However, this goal is too far from being achieved with current technology. Currently, mobile robots are utilized by borrowing human intelligence or by moving in simple environment in which only low-level intelligence is required to navigate. We think that the state of art in the mobile robotics area have only achieved good results when there is a help from human (tele) operator. Since the goal of mobile robot research is too far from present mobile robot technology stage, mobile robot in intelligent space may be a good sub-goal. In this case, the robots get intelligence/information, which the robot lacks, from the space. When human operator wants to operate the robot, he communicates with intelligent space and the space translates it to the robot. Especially, we also want to emphasize that the intelligent space is an intelligent system to support humans as well as robots.

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2. Mobile Robot and Space

We classified space into three types. Before describing intelligent space, we show our ideas about space.

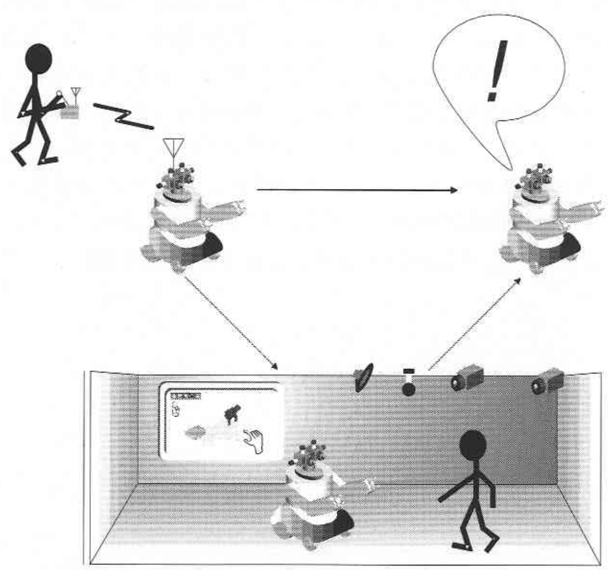


Fig. 1 Flow of mobile robot research

Potential Information Space This is a natural space. It has much information, however, to acquire the information from the space, a client needs high intelligence. Natural environment is an example.

Passive Information Space In this space, artificial signs are included in the natural space. A client needs less intelligence to acquire the information from the space. As an example, general living environment is considered.

Active Information Space Information is automatically afforded in this space. Since the space itself has intelligence, a client does not need any intelligence to get information from the space. The intelligent space comes under this space.

2.1 Intelligent Space

An intelligent space is an area such as a room, a corridor or a street that is equipped with sensors (ccd cameras, microphones etc.), actuators (display, speaker, etc.), information database, communication devices and computational ability. The intelligent space understands what is happening in it through its sensors and react through its actuators. It observes humans in it, recognizes their action/gesture and act accordingly. We have showed some examples of the intelligent space by technical papers.[1]

We built a basic level intelligent space in our laboratory that is used by students and researchers working in it.

2.2 Relation between Mobile Robot and Intelligent Space

Even though the space recognizes what human is requesting. It lacks an agent to handle real objects. Mobile robots execute tasks in the physical domain and the intelligent space can use a mobile robot as a physical agent for itself. Possible tasks include movement of objects, providing help to aged or disabled persons etc.

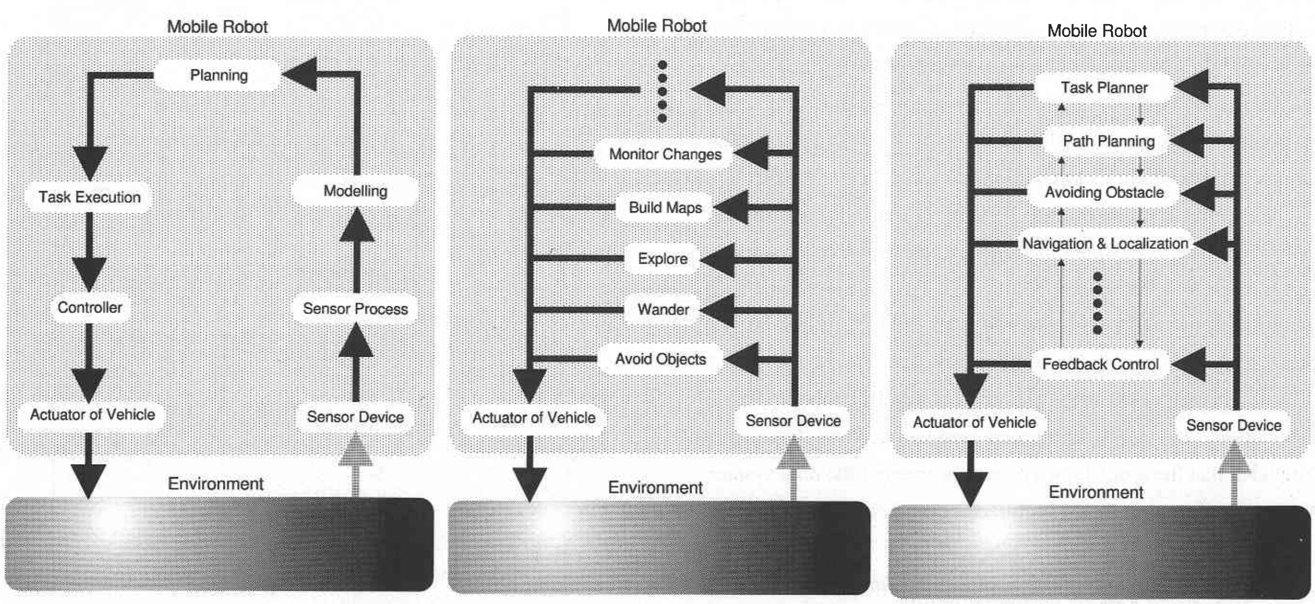
On the other hand, the intelligent space provides information and intelligence to the mobile robots. It is hardly possible for a mobile robot to realize these information and intelligence by itself. Extremely, if the toy follows communication protocol and has network device and basic computational ability, even a toy car can be used as a mobile robot in the intelligent space. This feature will be shown by experiments described in this paper.

3. Mobile Robot Architecture

3.1 Conventional Architectures of Mobile Robot

During the last twenty-five years, many mobile robotic researchers have spent lots of time on designing new system architecture for autonomous mobile robot. Those system architectures can be classified as three types.

The first one is called functional decomposition architecture or hierarchical architecture. This architecture has several separated functional modules and those modules are connected sequentially. As shown in Fig. 2 (a), the system composes a closed loop of information with functional modules and environment. This kind of architecture was well used in past mobile robots. Shakey robot



(a) Hierarchical architecture (b) Subsumption architecture (c) Hybrid architecture

Fig. 2 Mobile robot architectures

at SRI, CMU rover and Navlab robot used this architecture. However, due to sequential processing, overall processing time becomes longer and even one module can dominate performance of whole system.

The second one is called behavioral decomposition architecture or subsumption architecture. This architecture was proposed by Brooks.[2] In this approach, modules become meaningful behavior. Each slice of functional decomposition architectures are implemented and tied all together to form an autonomous mobile system. Fig. 2 (b) shows the subsumption architecture. The system is composed with competent levels and each level has a connection with sensors and actuators. This architecture has a ability to enhance the system only by adding a new behavioral level.

Many modern autonomous systems adopted the subsumption architecture. In behavior architecture, the layers hold the sensory information in common, and they must be independent each other. However, when we are developing a real system, it is hard to keep those rules completely.

The last one is called hybrid approach. This architecture is made from combining the former two architectures. Employing this architecture, we have more chance to construct more robust, flexible architecture for a mobile system. Its scheme is shown in Fig. 2(c). Oxford mobile robot by H. Hu[3], Kaelbling's architecture and Mitchll's Theo-agent architecture are the examples of this architecture application.

3.2 Mobile Robot Architecture for Intelligent Space

Those former three architectures are based on an premise that environment is passive and only inherent sensors on mobile robot can get information from environment. Those approach exclude environment from the architecture of mobile system. With these structures, most of mobile systems have been moved successfully only under restricted environments. In the other environments, its speed was remarkably slow or human operator was necessary to help its navigation.

If we want to utilize mobile systems in our daily life in near future, we have to change our current approach. Recently, many papers on new mobile robot architecture have been written. Such researches try to graft new technology on the typical mobile systems.

There are many possible architectures of mobile robot for intelligent space. It is still an opened problem and we have only concluded that the space must be seen as a part of the total system. We propose Fig. 3 as a new architecture of mobile robot in intelligent space.

The space detects the position of humans and mobile robots. Request through gestures and speech from humans are recognized by a recognition process and a task generator translates them into a task plan. According to situations, the intelligent space controls the connection of behavior layers in the mobile robot. A communication device transmits this information to the mobile robot. A behavior fusion process in the mobile robot generates its output by fusing the data from the environment and its behavior layers.

Only a low performance processor and few sensors are required in the proposed structure of a mobile robot. The proposed structure reduces overlapping intelligence and sensory information. Additionally in the case of a large number of mobile robots in a space the overall necessary amount of sensors and computation power is significantly reduced.

4. Experimental System

In this section, we explain our experimental system setup.

4.1 Mobile Robot and Color Bar-Codes

We use a holonomic mobile robot.[4] This robot can move omnidirectionally without any restriction except physical limit. However, it has very bad features for dead reckoning. Without gyroscope sensor, which costs more than four thousand U.S. dollars, the robot can hardly measure its directional angle. A photo of

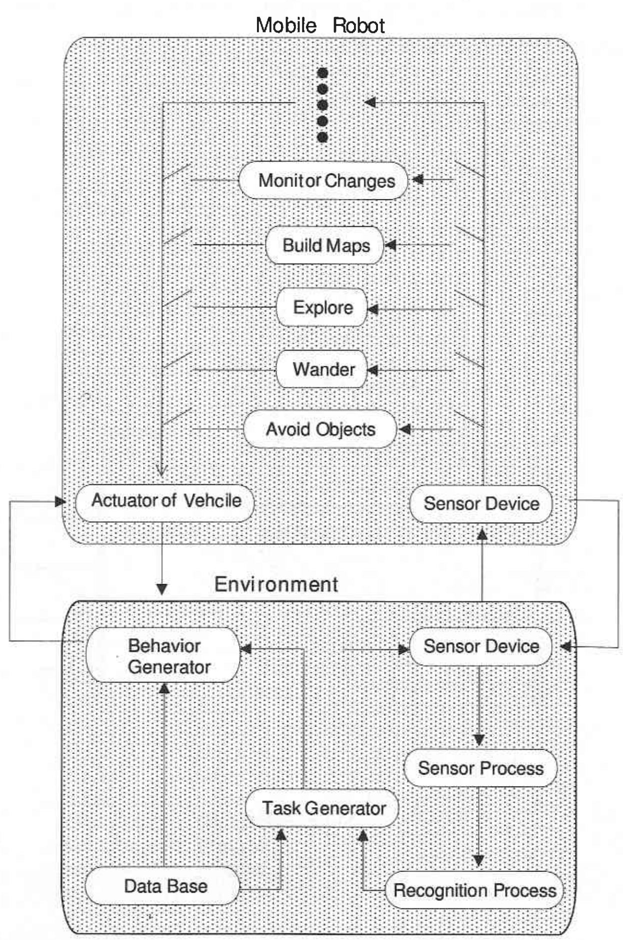


Fig. 3 Proposed Architecture of mobile robot in Intelligent Space

the robot is shown in Fig. 4 (a).

To locate the robots in the intelligent space, colored spherical targets (Fig. 4 (b)) at four corners on the top of robots are used. We use color bar codes that are located below the targets. The color bar code consists of two colored fields. Each of the fields can have one of the eight possible RGB combinations. With this technique, we are able to distinguish the targets over 10 mobile robots.

4.2 Vision System

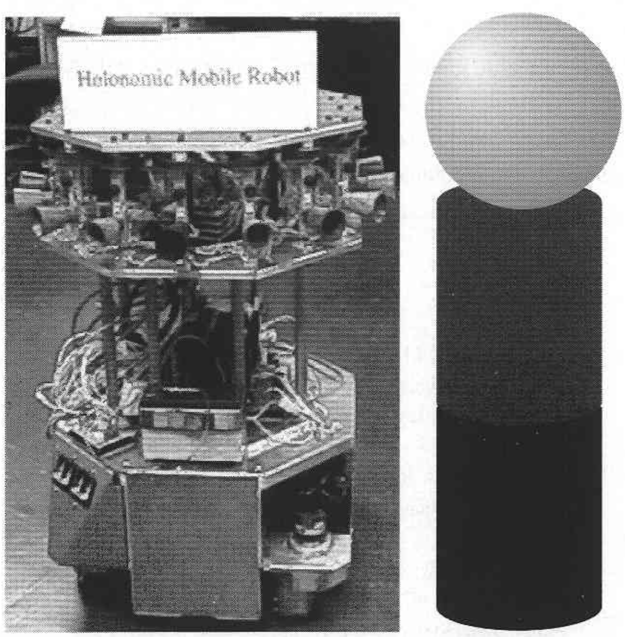
We constructed the vision system, which tracks objects in the space and generates coordinates of the objects. The vision system uses two basic techniques to do it. One is separating the shapes of the objects from image and the other is model based color matching. Refer [1] for details.

The output of the vision system is a list of 3D target locations with the corresponding color bar codes. If the height (z-axis) of the targets is known, only one camera is needed for a precise 3D construction.

4.3 Pose Detection

After target detection procedure, to get rid of errors, the 2D Euclidean distances between detected targets are checked. If the distance is too long or too short, the detected target will be neglected. Even after this, the result still may contain detection errors. Fig.5 shows that results, which are obtained by the former process, have one detection error in the table at the right part.

According to the database of the intelligent space, each color bar code is recognized and some targets, which are not shown in the list, are removed.



(a) Holonomic robot (b) Color bar

Fig. 4 Mobile robot and color bar codes

The geometrical relation, which was stored in a data base, is compared between the color bar-codes and it generates the pose of the robot. The pose of the robot is calculated from the pairs of color bar codes, with the same time stamp. The obtained results are averaged.(eq. (1))

$$P_{r,t} = \sum_{i=1}^{s} P_{i,t} \quad \cdots\cdots (1)$$

where P is pose of the robot, P is pose calculated from a color bar-codes pair, s is total number of possible pairs, and t is time.

4.4 Communication

Both intelligent space and mobile robot have communication devices and they communicate each other. The mobile robots send their resource including geological information of color bar codes, the height of colored sphere target, kinematic model and so on to the space. Based on that information, the space sends additive information to the robot.

Fig. 5 Target detection example

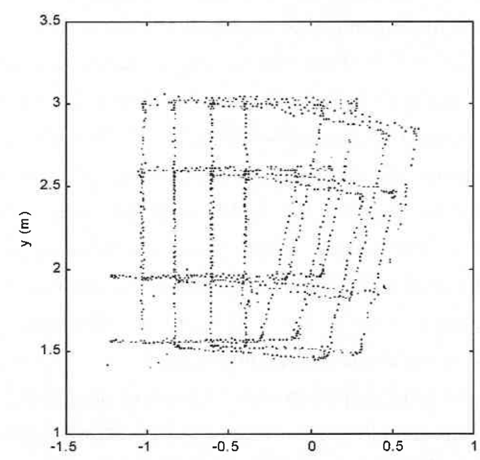
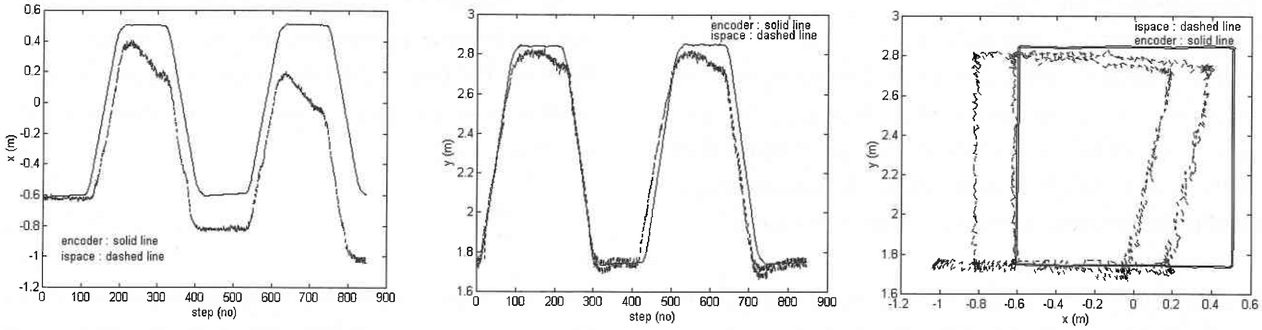


Fig. 6 Trajectory of color bar codes on top pf the robot



(a) Trajectory of mobile robot on x (b) Trajectory of mobile robot on y (c) Trajectory of mobile robot

Fig. 7 Trajectory of the holonomic mobile robot when it navigates twice on a square path without direction change

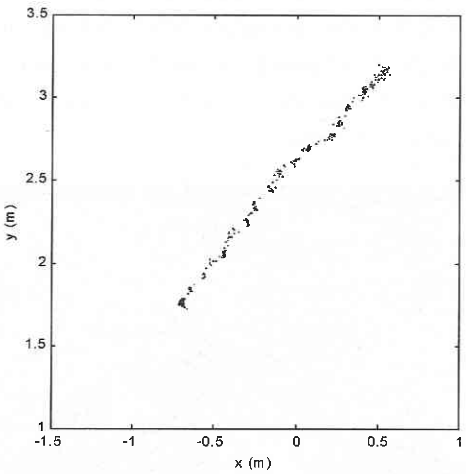


Fig. 8 Trajectory of the mobile robot with internal sensors are disabled

5. Experiment

In this paper, we will show two experimental results. The first one shows the possibility of using the intelligent space as a supporter of a mobile robot. The robot was programmed to follow a squared path making the same trajectory two times. The velocity of robot was about 10 cm/sec and the robot uses dead reckoning to localize itself. Fig 6 shows the trajectory of four colored spheres, which are attached to each corner of the robot. We could observe that the results include many errors. The trajectories of the mobile robot are shown in Fig. 7. The solid line is the trajectory calculated by the mobile robot. Since the robot uses only encoders for dead reckoning, it cannot sense slip and initial coordination errors. Even if the robot had a gyroscope, initial positioning errors could not be compensated.

The second experiment is to show an example of what the space can do for the mobile robot. In this experiment, we intensively inactivated self-localization behavior of mobile robot. Since it has no way to measure neither position nor speed, it is no more than a toy, which has a radio receiver. A human operator indicated a desired target point to the space then the space translated this information to the robot. The robot just followed the order from the space whether the output is correct or not. The space continuously tried to fix position errors of the robot and it finally reached the goal. Fig. 8 shows the trajectory how the robot got to the goal.

6. Conclusion

The current integration of perception and reasoning in many devices and their integration into networks will lead to environments that have an intrinsic intelligence. These intelligent spaces will provide humans with a high-level, multi-modal interface and eventually be able to take actions on their own. In this paper, we described the functions and roles of mobile robot as physical agents in an intelligent space.

Relation between environments and mobile robots are discussed and a new architecture for a mobile robot in an intelligent space was proposed. By some experimental results, proposed architecture was tested.

We do not think the architecture of a mobile robot described in this paper is the optimal structure. We think further studies are needed to improve the architecture.

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Reference

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