Supervised Hybrid Control Architecture for Navigation of a Personal Robot

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Abstract: As personal robots coexist with a person with a role to help a person, while adapting various human life and environment, the personal robots have to accommodate frequently-changing or different-from-home-to-home environment. In addition, personal robots may have many kinds of different Kinematic configurations depending on the capabilities. Some may have a mobile base and others may have arms and a head. The motivation of this study arises from this not-well-defined home environment and varying Kinematic configuration. So the goal of this study is to develop a general control architecture for personal robots.

There exist three major architectures; deliberative, reactive and hybrid. We found that these are applicable only for the defined environment with a fixed Kinematic configuration. Neither could accommodate the above two requirements. For the general solution, we propose a Supervised Hybrid Architecture (SHA), in which we use double layers of deliberative and reactive controls, distributed control with a modular design of Kinematic configurations, and real-time Linux OS. Deliberative and reactive actions interact through a corresponding arbitrator. These arbitrators help a robot to choose an appropriate architecture depending on the current situation to successfully perform a given task. The distributed control modules communicate through IEEE 1394 for the easy expandability. With a personal robot platform with a mobile base, two arms, a head and a pan-tilt stereo eye system, we tested the developed SHA for static as well as dynamic environments. For this application, we developed decision-making rules for selecting appropriate control methods for several situations of navigation task. Examples are shown to show the effectiveness.

Keywords: Personal Robot, Control Architecture, Deliberative/Reactive Hybrid Control, Modular Controller, Arbitrator

1. INTRODUCTION

The tasks of robots vary from simple/recursive assembly tasks for manufacturing automation to complicated exploration tasks in unknown environments. The task environments of robots also vary between static environments, such as an unmanned factory, to dynamic environments such as homes and buildings. This fact implies that the controller needs to satisfy complexity and flexibility from various tasks and the environments. The controllers of current robots are just appropriate for their limited application domains [1][2][3][4]. If these controllers were applied for other tasks, the additional cost to modify would be a lot. Especially for a new kind of robots, called personal robots, the controller additionally needs to handle many different configurations of kinematical functions or sensors. For example, a robot has just a simple mobile base and another has a head, two arms and legs. Consequently, personal robots need a controller to handle complexity of robot configurations and to satisfy flexibility necessary to cover various tasks and environments. This becomes the motivation of the current study.

As a solution, a reconfigurable modular distributed controller for personal robots is proposed in this study. It is composed of a main supervisory controller and several local modular distributed controllers. The modules are connected by IEEE 1394 to allow the expandability of modules and distributed control. For the operating system, a real-time Linux is used to reduce cost and to satisfy distributed and modular application by modifying the open source code. The proposed control architecture, based on new deliberative/reactive hybrid control architecture, is called as Supervised Hybrid Architecture (SHA) [5]. That is, SHA is proposed as a solution to handle complexity of robot configurations and to satisfy flexibility necessary to cover various tasks and environments.

This paper is organized as follows: in Chapter 2, previous relevant research is discussed and the requirements for new control architecture are derived. In Chapter 3, a new control architecture called SHA is proposed and designed. In Chapter 4, Experiments on the proposed SHA controller are explained. In Chapter 5, we conclude that the proposed control architecture can be an effective solution for personal robots, the various tasks and environments.

2. PREVIOUS CONTROL ARCHITECTURES AND REQUIREMENTS OF CONTROLE ARCHITECTURE

In this section, we analyze previous control architectures and derive the requirements of new control architecture for personal robots. Previous are divided largely into deliberative control architecture, reactive control architecture, and deliberative/reactive hybrid control architecture to combine the advantages of both deliberative and reactive control architecture.

2.1 The deliberative control architecture

The deliberative control architecture is one of the traditional robot control architectures and has been studied since 1960s [6]. This has a vertical computation style such as sense-plan–act. General characteristics of this deliberative control are same as following:

① Assumption that is not different between initial knowledge and actual information must be satisfied for success of tasks.

② When ① is satisfied, it can apply to tasks that require high-level intelligence and action result of robot can be predicted.

③ It can't cope fast in change of environments.

④ Because a lot of modeling information is used, it need much time for a action creation.

2.2 The reactive control architecture

The reactive control architecture is devised to improve drawbacks of deliberative control architecture by Rodney Brooks in the 1980s at MIT University. This has a horizontal computation style such as sense-behavior-act [7][8]. General characteristics of this reactive control are same as following:

① It is possible to apply in unknown or dynamic environment.

② It can respond instantly to sudden change of environment.

③ Because information of current sensors is used only without any initial knowledge, the intelligence is limited.

④ It is hard to predict results of action and a next situation.

2.3 The deliberative/reactive hybrid control architecture

The deliberative/reactive hybrid control architecture [9][10][11][12] is devised to improve drawbacks of the deliberative control architecture and the reactive control architecture. This hybrid control architecture is combined deliberative control architecture and reactive control architecture and can has characteristics of all area between these two control architectures. These use deliberative controls for high-level control such as planning and studying and reactive controls for low-level control such as motion of robots. Therefore it is possible to soft control in dynamic environment and to implement high-level intelligence simultaneously. Because of these reasons, robots that are applied in real world have most this hybrid control architecture. The hybrid control architecture has various merit/demerit according to a fusion configuration of deliberative control and reactive control. So it can be suitable several kinds according to tasks that robots are applied. The kinds of deliberative/reactive hybrid control architecture are classified according to fusion configurations in Fig. 1.

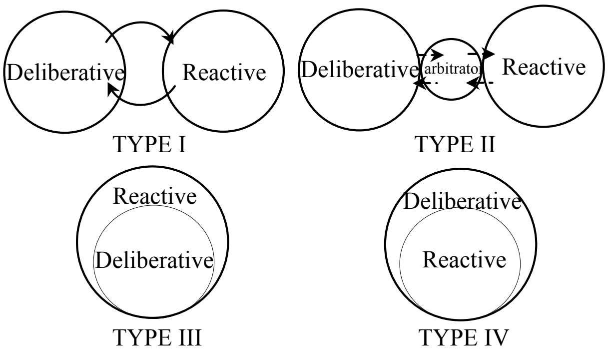

Fig. 1 Various hybrid control architectures

① TYPE 1: This type is a fusion configuration that is separated into a deliberative control layer and a reactive control layer perfectly. And these two layers operate independently. Hence design of this control architecture is easy, but this type isn't efficient in implementation of intelligence such as adaptation because of separation of two control layers.

② TYPE 2: This is similar to Type 1 except an additional arbitrator between deliberative and reactive layers. This arbitrator enables role exchange of two layers smoothly and can allow tasks that need booth layers at the same time. This arbitrator provides a key strength of this type because it can decide what motion among deliberative and reactive behaviors to be activated. This type was used in the robot Sojourner for the Mars exploration task of NASA [13].

③ TYPE 3: Here a deliberative control layer is included as a subset of a reactive control layer. The deliberative control layer improves effectiveness of the reactive control layer by using partially correct world model. Since the main layer is reactive, implementation of high-level intelligence is still difficult. This type was used in the AIBO Japanese dog robot [14].

④ TYPE 4: Here a reactive control layer is included as a subset of a deliberative control layer. The reactive control layer improves performance of prompt reaction of the deliberative control layer. Since the main layer is deliberative, it may still not efficient in a very dynamic environment.

General characteristics of this deliberative/reactive control are same as following:

① The hybrid control architecture is soft in change of environment and has high-level intelligence.

② When the hybrid control architecture is designed, a fusion configuration is decided according to task and task environment that a robot are applied.

2.4 Requirement of control architecture for personal Robot

We find that existence of the arbitrator in TYPE 2 is very helpful in providing the flexibility for personal robots that need both deliberative behaviors for high-level intelligence as well as reactive behavior in dynamic environments. The additional issue is to design an arbitrator. For personal robots, however, a simple system with one deliberative layer, one reactive layer, and an arbitrator is not enough to cover all kinematical and sensor configurations and various tasks at home. These complex characteristics of personal robots configurations and tasks can be summarized as follows:

(1) Personal robots may have many different robot configurations of the kinematical and sensor modules. For example, one can have only a mobile base. Some can have a head module in addition and others can have arms in addition. As the robots are considered to be composed of several modules of a mobile base, arms, head, sensors units, and so on, the architecture has to be able to handle the complexity of diverse robot configurations.

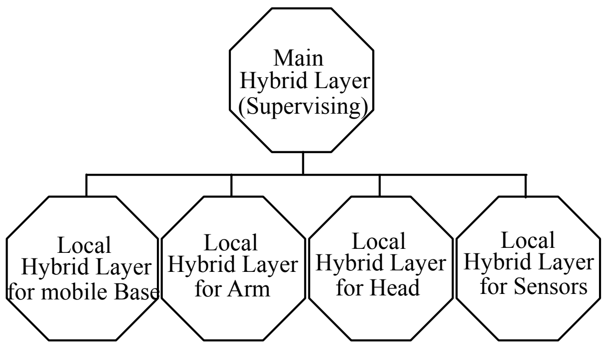

Fig. 2 A supervisory controller and local distributed controllers for a robot configuration

This first characteristic requires that the controller be of distributed hardware and software for all reconfigurable modules to be expandable. This implies that each module needs a local controller for local intelligence. To coordinate all local distributed controllers, there must be a main supervisory controller. This configuration will look like that in Fig. 2. The main supervisory controller determines high-level intelligence such as task planning. Thus, it can be regarded as a main hybrid layer, while modules of local intelligence can be regarded as a local hybrid layer.

(2) Personal robots may have to perform many different tasks. They include exploration, guidance, transportation, cleaning, surveillance, playing with children, and teaching children. Since these tasks are different from each other and may be too varied for one company to program, it is better for each task to have a corresponding module. In other words, it is better for each task to have its own hybrid combination of deliberative layer and reactive layer. Then, if a task is assigned, the control will be reconfigured to become one of hybrid control architectures in Fig. 3. In this way, the architecture can provide enough flexibility for diversity of tasks.

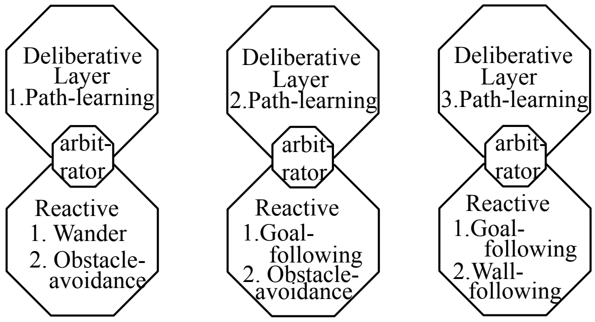

Fig. 3 Hybrid controls of Type 2 for various tasks

This second characteristic requires that the controller consist of many hybrid architectures of TYPE 2. That is, all candidates of task will have the corresponding deliberative and reactive layers connected by an arbitrator. The deliberative and reactive layers will exist separately and will be combined to form one as in Fig. 3 when a task is assigned. Therefore, the total will look like that in Fig. 4.

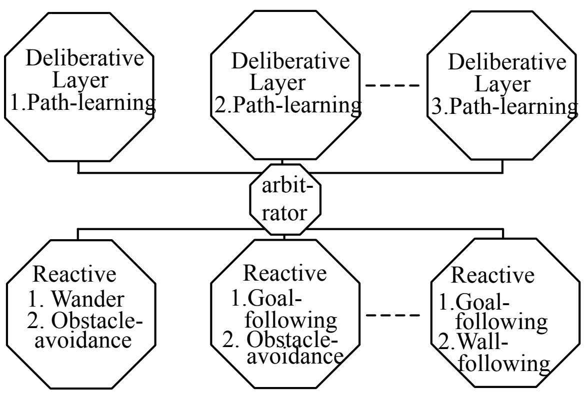

Fig. 4 Hybrid control architecture with many tasks

We derived two requirements for the control architecture of personal robots that are necessary for the handling of complex robot configurations and for providing the flexibility needed for diverse tasks. From the analysis of the requirements, it is concluded that personal robots need to be distributed and modular control architectures to combine the results in Fig. 2 and Fig. 4 into one comprehensive control architecture. In the following section, we propose our design of the control architecture that satisfies the requirements for the personal robots.

3. PROPOSED CONTROL ARCHITECTURE FOR PERSONAL ROBOT

In this section, we introduce our designed control architecture for personal robots. It is called the Supervised Hybrid Architecture (SHA). First, we summarize the design criteria for the SHA. Second, the hardware and software configurations are described. Third, we show how SHA is designed. Finally, we show how it works for different navigations.

3.1 Design Criteria of SHA

The design criteria for Personal robots can be summarized as following:

① Flexibility: Enough flexibility is necessary to handle various robot configurations and to accommodate various tasks. In addition, it has to be easy to add hardware modules and tasks.

② Modularity: Hardware and software need to be modular for the architecture to be flexible and for 3rd party to be allowed to add additional modules.

③ Real-time performance: This is important to make robots respond promptly to varying environment.

④ Reliability: This is more important for personal robots because they dwell with human beings.

3.2 Hardware / Software Configuration

To satisfy the criteria, the hardware and software are configured as follows.

3.2.1 Hardware Configuration

Our personal robot system has a mobile base (2 DOF), a head module (3 DOF), two arms (8 DOF), two hands (2 DOF), a stereo vision system, 16 ultrasonic sensors and 8 infrared sensors. All of these kinematic and sensor configurations are made modular for easy addition and removal of modules. The controller is designed based on this hardware configuration. It is a completely distributed modular design as in Fig. 5.

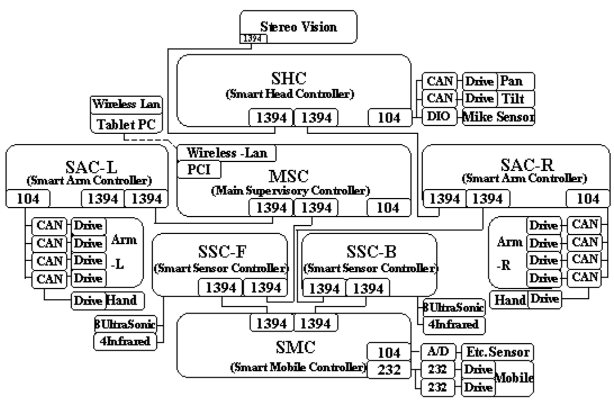

Fig. 5 H/W configuration of controller

This H/W configuration has characteristics as following:

① H/W is composed of a main supervisory controller and several distributed local modular controllers. Main supervisory controller coordinates all local controllers, while local controllers take care of local kinematic or sensing modules. Local controllers can be added or removed simply.
② All controllers are connected by IEEE 1394 communication for fast transmission of information and simple expandability of various modules [15].
③ Motor drives are connected by CAN(Controller Area Network) communication. This is also for simple expandability of additional degrees of freedom [16].
④ Wireless LAN is installed for remote control.

3.2.2 Software Configuration

The S/W configuration is shown in Fig 6. It has following major characteristics to satisfy the design criteria.

① Operating system of controllers is a Linux OS and a Real Time Linux. It has advantages of prompt response, low cost and open source [17].
② S/W of controller is also distributed and modular, so that tasks and robot configuration modules can be added and removed simply.

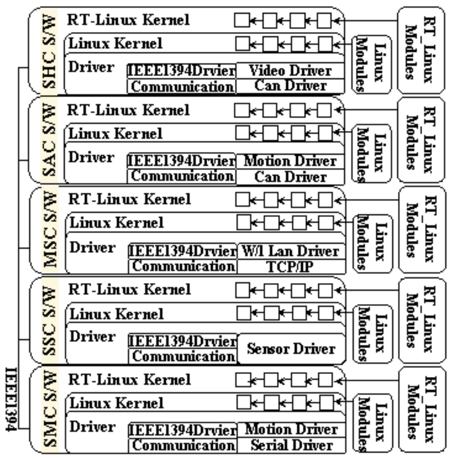

Fig. 6 S/W configuration of controllers

3.3 Design of Supervised Hybrid Architecture

With the hardware and software configurations, we design a new Supervised Hybrid Architecture (SHA) based on the deliberative/reactive hybrid control architecture.
To satisfy two requirements in Section II and design criteria in Section III, SHA is desired to be of the architecture in Fig. 7. This is a way to combine two diagrams in Fig. 2 and 4. As a result, our design of SHA has double layers of main hybrid layer (high-level) and local hybrid layer (low-level).
The main hybrid layer is composed of a main deliberative and a main reactive control. The main deliberative control supervises all while interacting with users and acts as a high-level intelligence. The main reactive control takes charge of communication of the corresponding robot configuration modules. Also the local hybrid layer is composed of several local deliberative and local reactive controls. The local hybrid control corresponds to separate and independent local intelligence. In this way, the double layer SHA is designed as in Fig. 7.

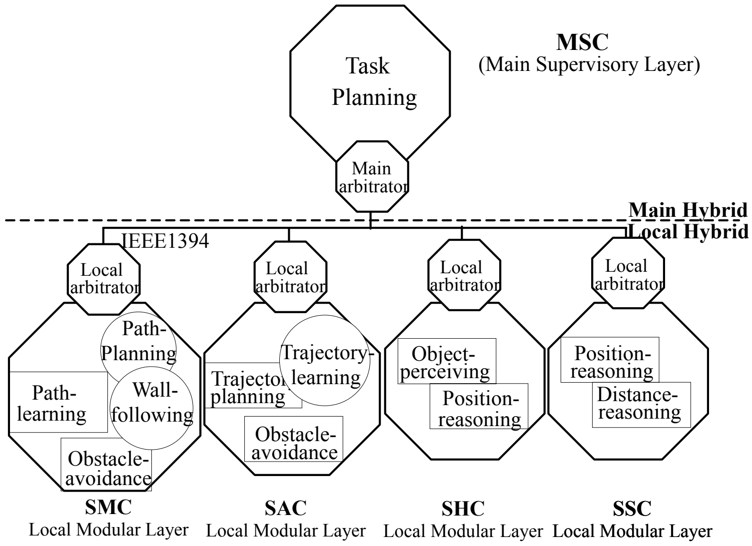

Fig. 7 A concept diagram of designed the SHA

The main hybrid supervisory control has a main arbitrator and each local hybrid control has a local arbitrator. This main hybrid control supervises through this main arbitrator to determine which local hybrid controllers will be chosen and functions will be assigned to them. Therefore the main arbitrator coordinates all local hybrid controls. The local arbitrators determine what motion to choose between the local deliberative and local reactive behaviors. When tasks are given to robot, the arbitrators perform as following Fig. 8.

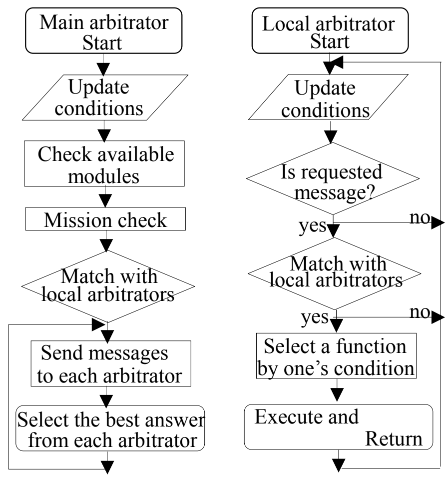

Fig. 8 Flow chart of Main/Local arbitrators

① The main arbitrator has functions as following:
   a. The main arbitrator reviews conditions of recorded information from shared memory
   b. It checks available modules.
   c. It checks a required mission by user.
   d. It will send messages to local arbitrator.
   e. It selects the best answer from each arbitrator.
   f. It observes one's conditions through local arbitrators.
② The local arbitrators have functions as following:
   a. The local arbitrators review conditions of recorded information from shred memory
   b. They receive massages from main arbitrator.
   c. They perceive to current environment with interacting local modules and select suitable control architecture in the environment.
   d. The tasks are progressed by priority sequence.

3.4 Navigation Using Supervised Hybrid Architecture

In this section, we show how the SHA works for the two navigation tasks. Our robot assumed that takes advantage of recorded world model. The navigation tasks are performed by each way at different environments

Situation 1: The navigation task in day environment

The current environment is decided by local head arbitrator. The main deliberative gets the information of all necessary modules. That includes the local mobile controller for mobile base, local sensor controller for ultrasonic/infrared sensors and local head controller for stereo eye system. In this case, Task-planning of main deliberative, Path-planning and Object-perceiving of local deliberative and Goal-following, Obstacle-avoidance and Distance-reasoning of local reactive are selected as in Fig. 9.

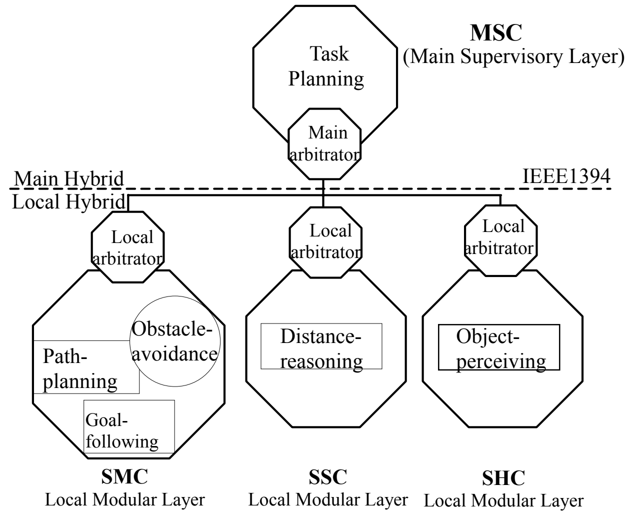

Fig. 9 Configuration for navigation in the day

Situation 2 : The navigation task in night environment

In this environment, the task is performed by the position of fluorescent lights mainly in the building. That includes local controllers for the mobile base, ultrasonic/infrared sensors and stereo eye system. In this case, Task-planning of main deliberative control, Path-planning, Path-learning, Object-perceiving and Position-reasoning of local deliberative control and Goal-following, Obstacle-avoidance and Distance-reason of local reactive control are selected as in Fig. 10.

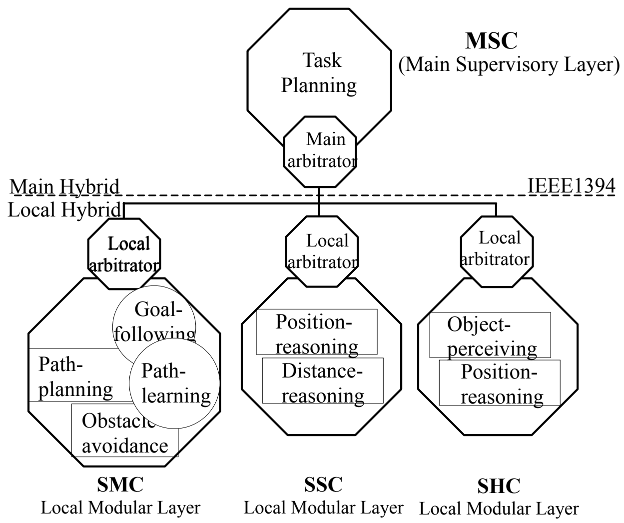

Fig. 10 Configuration for navigation in the night

4. IMPLEMENTATION AND EXPERIMENT

The designed double layer SHA is implemented in our personal robot to show the efficiency. In last chapter, we compared the navigation tasks in two other situations. The navigation tasks were performed on the hallway of a building at Kwangwoon University.

(1) The experiment in day environment

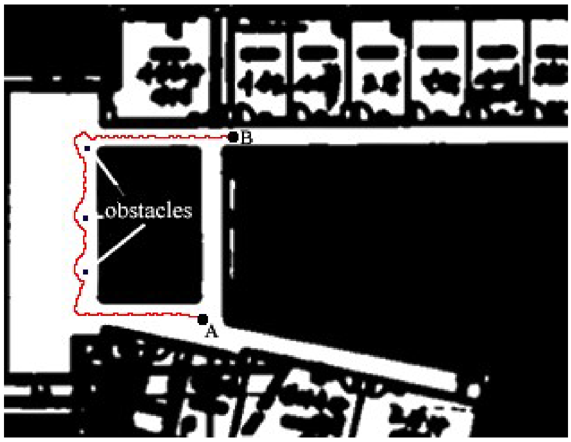

Fig. 11 Experiment result of Situation 1

The environment stands on the basis of world model for deliberative control. There are some obstacles which are not notified. The details of task are performed as follows. First, the main arbitrator does Task-planning from A to B position and the local arbitrators recognizes current environment. The local deliberative control starts to plan the path from A to B position and takes the robot to the planned position. When the robot starts to move, current position of robot is compared to the planned path of world model. Here a mobile base has inaccurate position data and sensors have relative correct position data by mapping with map based on data of the mobile base. So we gave the highest priority to local sensor arbitrator. By comparing the data of local mobile arbitrator and local sensor arbitrator, the position is supposed and reformed. Such as above, the robot moved from A to B position shown as the Fig 11.

(2) The experiment in night environment

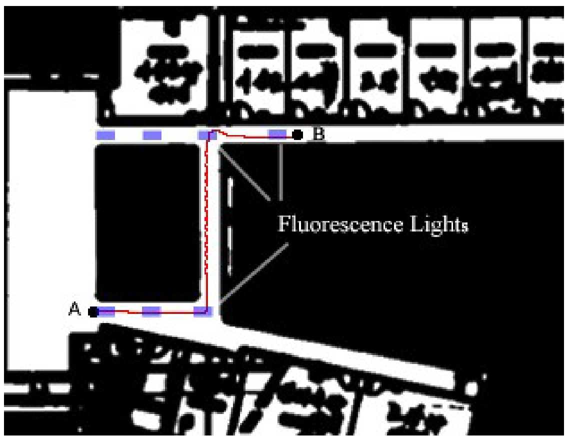

Fig. 12 Experiment result of Situation 2

The program and the place are same of A experiment. But the data of local head arbitrator is selected preferentially. In other words, the position data are measured by local mobile arbitrator, local head arbitrator and local sensor arbitrator. In the environment, the local head arbitrator is most trustful if we consider the fixed position of fluorescent lights. By comparing the data of local mobile arbitrator, local head arbitrator and local sensor arbitrator, the position is supposed and reformed. Such as above, the robot moves from A to B position shown as the Fig. 12.

We have performed navigation tasks in two ways. Both situations were performed successfully. These situations, however, may not be able to show the total efficiency of the proposed SHA. Therefore we will perform efficient tasks in more various ways and improve the efficiency of the proposed SHA.

5. CONCLUSION

In this study, we propose a supervised hybrid control architecture motivated by the need for both the handling of a complex personal robot configuration and the providing of enough flexibility for many different tasks. To satisfy these requirements, the control architecture is designed to have two layers (main hybrid and local hybrid).

The main hybrid layer has high-level intelligence with a main deliberative control of task planning and a main arbitrator, as well as low-level intelligence with main reactive controls for distributed local modules of mobile base, arms, heads, and sensors. These modules are reconfigured based on a given robot configuration and a given task.

The respective local hybrid resides in the distributed local modules of the main reactive control. Each has local deliberative controls, local reactive controls, as well as a local arbitrator. What deliberative and reactive controllers should be used is decided based on a given task and the availability of a necessary world model. Even though the local hybrid has local deliberative control, the global behavior of each module is like a reactive control from user's point of view at the highest level.

This reconfigurable and distributed feature of double hybrid control with main hybrid and local hybrid facilitates the development of robots by several companies or institutes. That is, it is possible to easily attach an arm developed by other companies. Modules can be tested simply because it is easy to add and remove local modules. In addition, our SHA corresponds to one of the most general control architectures, so that it can cover most of the intelligences necessary for personal robots.

SHA was implemented and tested for navigation in each different way. Our robot could perform the tasks successfully, and showing that SHA works effectively.

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