A Mobile Robot for Service Use: Behaviour Simulation System and Intelligent Control.

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Abstract: The structure of hardware and software of AI control system of a mobile robot for service use are described. Hardware of a mobile robot for service use include an autonomous wheel vehicle and a five degree of freedom manipulator. Software of AI control system of a mobile service robot is based on soft computing including fuzzy control rules, fuzzy neural network and genetic algorithms. Intelligent control of cooperative motion between of an autonomous vehicle and a manipulator realize the flexible operations as navigation of a mobile robot in presence of static and dynamic obstacles, the processes of opening door in rooms and push button of elevator. New hierarchical structure of AI control system includes direct human-robot communication line based on natural language and cognitive graphics, and generator of virtual reality for simulation of artificial life conditions for mobile service robot. Simulation results and experimental results of navigation and technological operations with manipulator for mobile robot of service use in office building are described.

1. Introduction

The structures of hardware and software for fuzzy control of an intelligent robot for service use in office

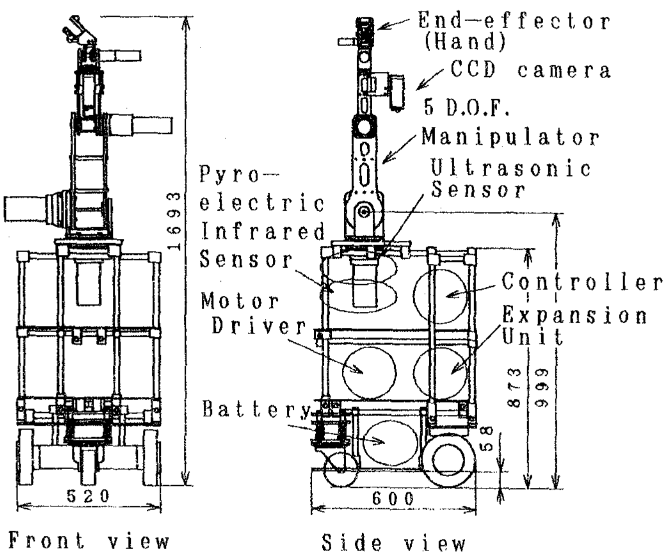


Fig. 1. View of a developed robot.

building was developed in papers [1-7]. This rob power-wheeled steering type which is achieved by driving wheels and a caster with passive suspen for stable locomotion. Thirteen ultrasonic sens nine infrared sensors, a five degree-of-freedom nipulator with a three finger hand and a CCD c era are equipped on the robot for conducting t and works in office buildings including human b opening door and getting on a elevator (see Fig.

In this report we discuss in detail the applicat of soft computing algorithms [3,5] based on fuzzy ulation, fuzzy neural networks (FNN) and geneti gorithms (GA) for intelligent control of mobile r for service use. This approach to intelligent co of cooperative motion between of autonomous cle and manipulator realize the flexible operatio navigation of mobile robot in presence of static dynamic obstacles, the processes of opening do rooms and push button of elevator.

New hierarchical structure of AI control sy was developed (see Fig. 2) it includes: 1) d human-robot communications line based on na language (NL) and cognitive graphics (CG), 2) g ator of virtual reality (VR) for simulation of arti life conditions for mobile service robot, and 3) ule of intelligent control of a mobile robot for se use on executive levels. The structure of this human-robot communications line was describ [1,3].

In this report we describe more in detail the ware of human-robot communications based on temporal logics, action logics, and default logic necessary and sufficient conditions for semant scription of *external* world representation in ator of artificial life of mobile robot for servi [2,3,5].

Simulation results and experimental results igation in presence of obstacles and technologic erations with manipulator for mobile robot of s use in office building are described.

2.The Structure and Mathematical ground of Direct Human-Robot C munications and Behavior Simul System

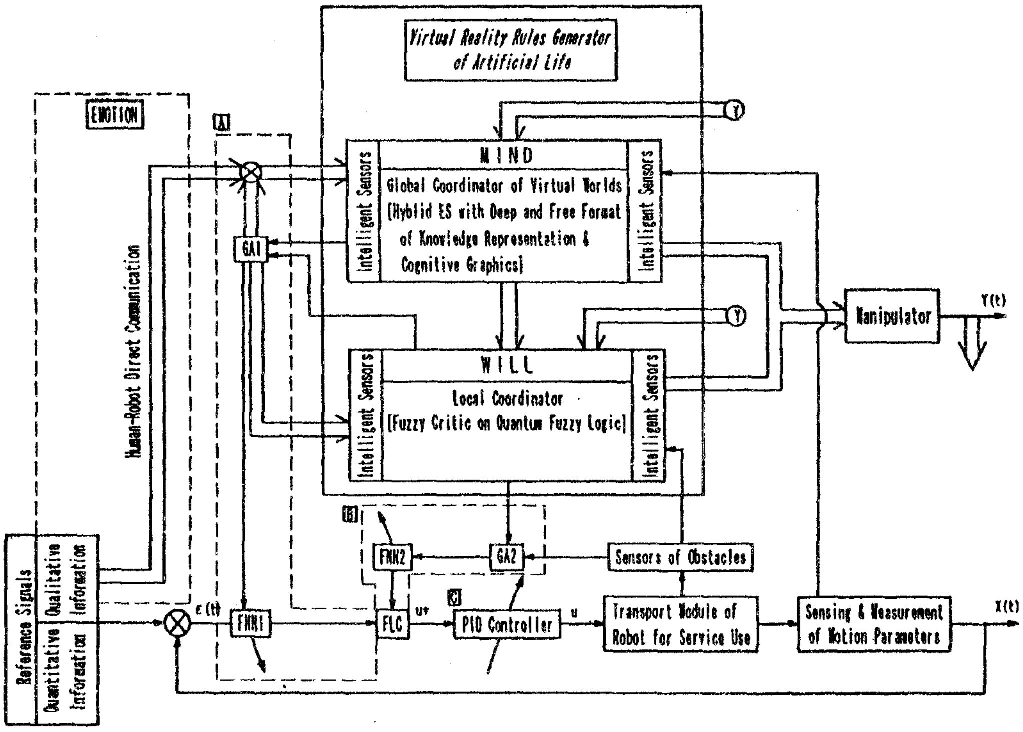


Fig. 2. Structure of AI control system with distributed knowledge representation.
A : Intelligent control " in large " ; B : Intelligent control " in small " ;
C : Control on executive level.

Applications of NL and CG for condition description of robot artificial life and direct human-robot communications for a mobile service robot are considered in [1,3] . Here we discuss the structure of behavior simulation system of a mobile robot for service use and design problems based on spatio-temporal and action logic for intelligent decision-making and approximate reasoning of a mobile robot for service use. VR is used for description of possible *external* worlds simulation in artificial life of mobile robot. This allows to evaluate the control algorithms of real time robot behavior and to reduce difficulties connected with such troubles as robot collisions with real objects in instructed environment and robot hardware damages. The mathematical background of robot behavior simulation system is knowledge engineering based on spatio-temporal and action logics, default reasoning, CG and soft computing [1-3].

2.1. Task Definitions

Human operator describe the artificial life conditions of a mobile robot for service use on NL. These condition descriptions include: 1) An environment scenes description (for example, some room in the building, the objects in this room, the fuzzy spatial relations between its, and so on); 2) The scripts of robot artificial life as the set of actions (for example, actions as " go to the room "; "show image of the room"; "open the door"; "grasp the book on the table"; "put this book near to computer" and so on).

We consider the set of instructions for mobile robot on the NL-text as human-robot communication input that describes environment situations in space and in time [3,8]. The NL-text is transformed into internal representation (IR) of simulation computer system. Based on IR and knowledge about spatio-temporal relations and actions the system can generate and visualize the 3D graphical images corresponding to the NL-input [1,2].

2.2. Main Concepts and Structure of Simulation System

The robot behavior simulation system structure is represented on **Fig. 3**. The system consists of the following modules: 1) menu interface with NL-language interpreter module ; 2) planning module of robot behavior in the environment scenes with 4 blocks: - the planning of robot action (Block1); - the analysis of robot's action from the stand-point of qualitative physics, spatio-temporal and action logics (Block2); - the construction of the set of scenes as mapping of the environment changes connected with actions (Block3); - the mapping of scenes description into IR (Block4); 3) Tools for mapping and change of simulation environment scenes including: - Graphic

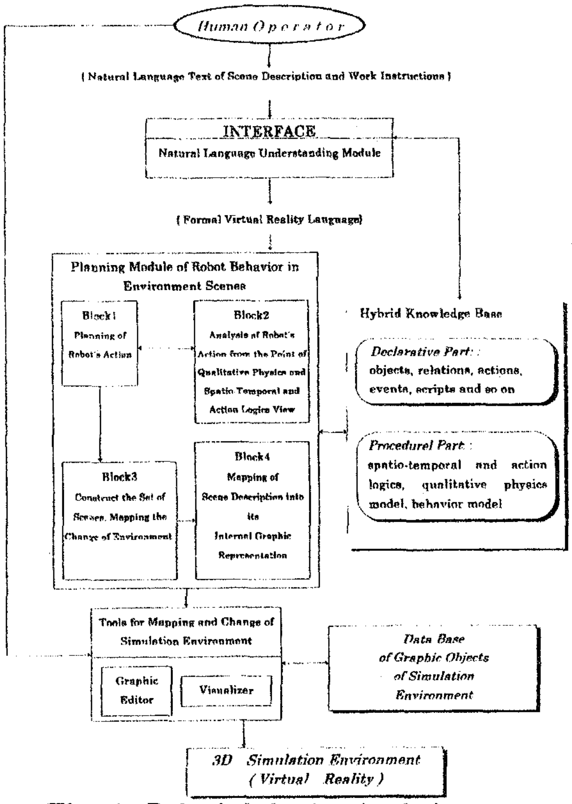


Fig. 3. Robot's behavior simulation system.

Editor and Visualizer; 4) Knowledge and Graphic object bases. The NL-text input describes the 3D spatial scenes (for examples, rooms) with objects and spatial relations between its and contains the work instructions for robot what is necessary to do in these scenes. Robot may act and change spatial scenes. We introduce the concepts of *static spatial scene* and *dynamic scene*. The static spatial scene description represent *the set of objects* connected with each other by *the definite spatial relations*. The dynamic scene description consists of *initial spatial scene* description and *actions* description. To simulate such environment we develop [2,8] the formal language for description of environment scenes (as VR scenes) and its change according with robot's actions named as VR language - VRL. The following *basic notions* are considered: times, 3D points, spatial localizations, spatial scenes, scripts ; *actions and external influences* and *basic relations*: temporal, spatial, causal relations and case relations for actions.

2.3.The Problems of Spatio-Temporal and Action Logics Design for Intelligent Decision Making and Approximate Reasoning .

If robot for service use can be able to plan its actions then its behavior intelligent level will be increased. In this case robot can be able to understand spatio-temporal relations, to reason about the consequences of actions and foresee the changes that its actions bring forth in the real world. We developed a reasoning and planning module of robot's decision-making that realizes these three abilities (to understand,to plan and to foresee). The approximate reasoning system is based on so named pseudophysical spatio-temporal and actions logics in which neither real physical and metric properties of time, space and action nor human perception properties in axioms and inference rules are used. For behavior simulation of intelligent robot for service use we modify the logics developed in [8]. The examples of experiments (see below) shows the effectiveness and adequacy of proposed logics to solution of given task.

For more complex description of action and planning mechanism included different conditions, events and procedures we use the script notion. Script is the special structure for knowledge representation connected with some set of actions (for example, the script "to move itself by the elevator"). So, the planning and reasoning mechanism based on action logics and scripts more complex and powerful. And behavior of robot for servise use based on this model more sophistic and intelligent.

2.4. Example of Simulation

By the direct human-robot communications line on NL robot recieves the following command on NL-input : "The room number 117 is situated at second floor of building. The desk is in the center of this room. The chair is left from the desk and near to it. The lamp is on the desk. Go to the room number 117, take this lamp and put it on the wardrobe." By the behavior simulation system, robot may plan the set of its action and also construct the graphical representation of described room (that may be considered as global map (image) of this room). **The Fig.**

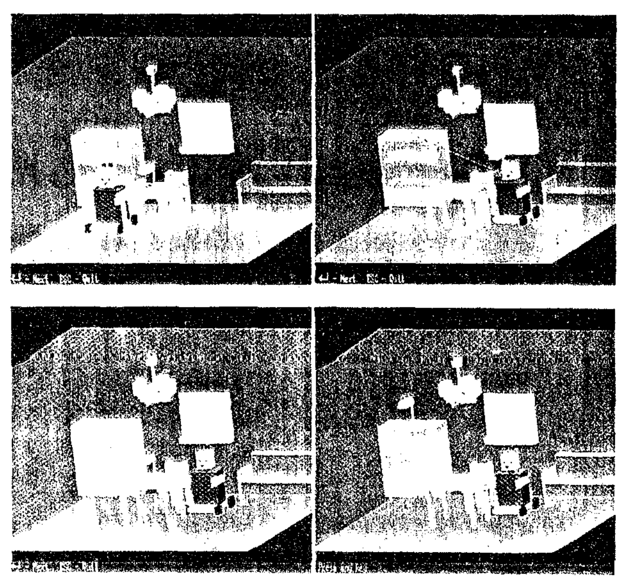


Fig. 4. 3D visualization of dynamic scene.

4 shows the 3D graphical representation of dynamic scene described by the NL. Such simulation system allows us to examine and correct the different algorithms of task level planning, navigation of robot for service use and direct human-robot communications on NL.

The output information of simulation system is input for managing control locomotion system of second level (see **Fig. 5**). The structure on **Fig. 5** presents the main modules of autonomous locomotion control system. Consider in detail the main modules of structure on **Fig. 5**.

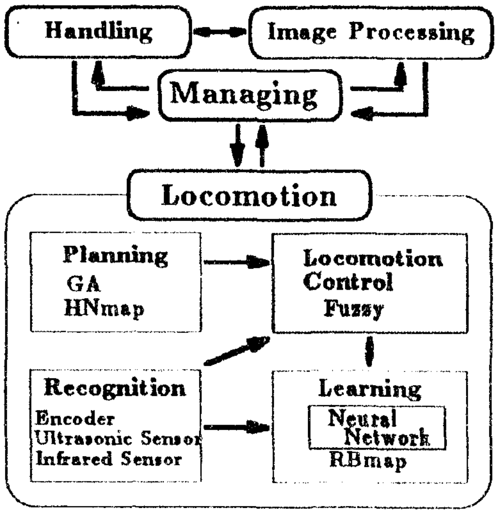


Fig. 5. Autonomous locomotion control system.

3. Soft Computing for Autonomous Navigation and Technological Operations

3.1. Managing System

The intelligent control system of this service robot involves three sub-systems, as locomotion system, handling system for manipulator and image-processing system. The robot behavior simulation system describe the set of its actions, as the input for *managing system*. This managing system is organized mainly by *scheduling system* which plan a work file autonomously based on hierarchical node (HN) map method and GA [3-7]. In the work file, aimed tasks or works (for example, openning a door and operating an elevator) and the target point for its are described sequentially in each area (corridors, rooms, elevator and so on) as the following: [*Move Command* : *Work Command* : *Area*]. where, *Move Command* is a command to locomotion system, a start and a target point. *Work Command* is one to handling and image-processing system. For example, in a case of using HN map shown in **Fig. 6**, when the following command is given to behavior simulation system: " **Go to node 34 (elevator)** ", the following work file is planned by managing system:

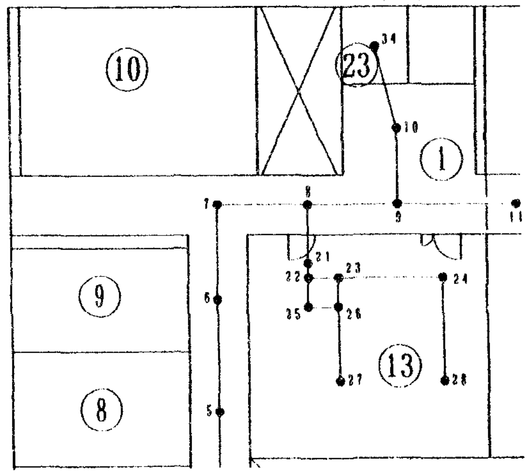


Fig. 6. HN map for planning a work file.

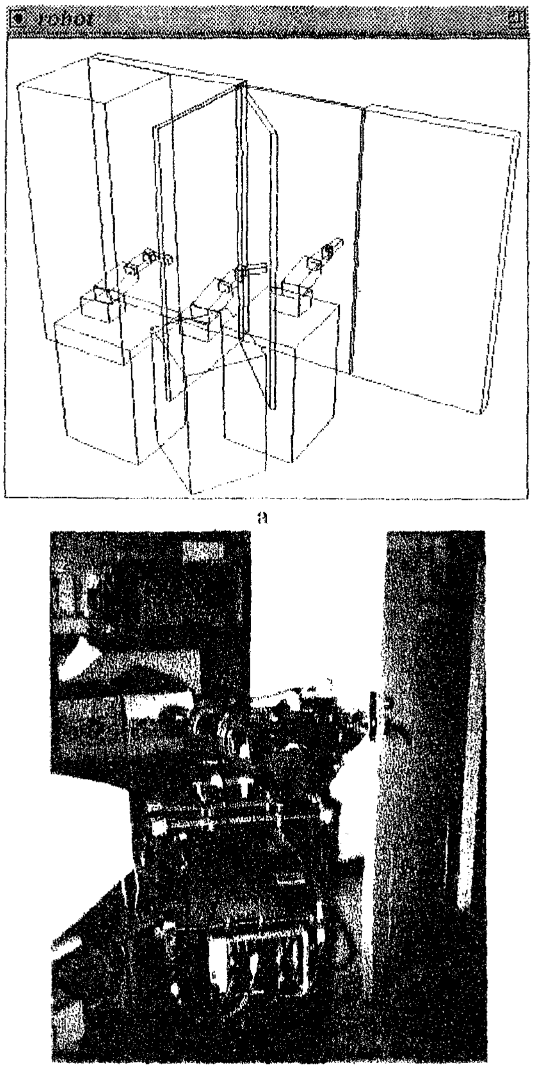
GOTO-0026-0021 : PULL-DOOR : AREA-0013
GOTO-0008-0010 : GETON-ELV : AREA-0001
GOTO-0034-0034 : MOVE-TRGT : AREA-0023

The robot can move continuously from a room (node 26) to an elevator (node 34) with this work file.

3.2. Technological Operations with Autonomous Locomotion

By using the work file planned by managing system, three sub-systems are controlled properly one after another. In autonomous navigation with the above work file, at the first, the robot moves in front of a door (node 21) with avoiding obstacles by using fuzzy logic and FNN [4,6,7]. And the next, it opens a door by handling system based on *Work Command* 'PULL-DOOR', and goes out a room (area 13) to elevator (node 10). Lastly, it pushes an elevator button, gets on it and completes a command. Where, in one task or work, there are global and local process. The global process contain a global path planning and a fuzzy locomotion with tracing path- and avoiding obstacle control. The local process has some technological operations, as opening a door and operating an elevator, including local achievement, manipulation and image processing. In this part, we describe the local process, as opening a door using GA and FNN, as one of technological operations and represent briefly an expample of autonomous nabigation control in the below.

Evolutionary process of opening a door using soft computing on GA and GACS in [3] is described. In this case it is reported that very effective integration of GA and FNN computation were carried out. We describe results of computer simulation and real experiments on a developed robot. A typical trajectory of opening door motion produced by GA is shown in **Fig. 7**. **Fig. 7a** is a 3D graphics of a simulation result. **Fig. 7b** is an experimental result on de-



a

b

Fig. 7. Examples of a trajectory through a door. a : Simulation results; b : Experimental scene.

veloped robot. Thus, the mobile robot succeeded in opening a door. If the mutation rate was large, both GA and GACS converged quickly, because we used *elite* strategy which simply always retained the best chromosome out of the population. When crossover rate was large, GA converged quickly, but GACS did not so. It shows that mutation is more important than crossover on GACS. We have compared GA and GACS, and confirmed that each algorithm had the following merits as well as demerits. In particularity **GA**: (1) strong in local optimum, (2) weak in local search, and (3) crossover is important to accelerate convergence. **GACS**: (1) strong in local search, (2) mutation is more important than crossover in order to accelerate convergence, and (3) weaker in local optimum than GA.

We introduce new approach for position calculation of mobile robot. We use GA together with FNN. In this case, FNN use a trajectory making by GA as

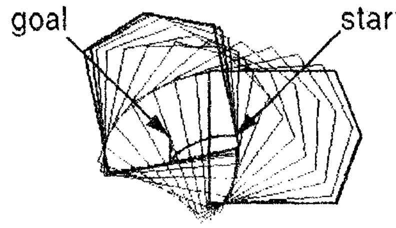


Fig. 8. Trajectory of FNN.

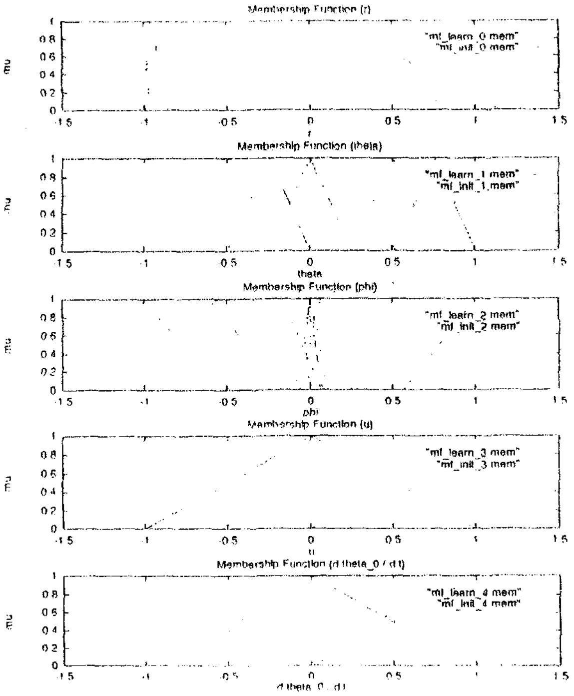


Fig. 9. Membersip function before / after learning.

teaching signal. A trajectory using FNN is velocity and angular velocity. **Fig. 8** shows the results of simulation after learning. **Fig. 9** shows the membership function before and after learning. The mobile robot position uses in simulation 320 goal position as random number. The results of simulation show that the distance error is within 10mm and within 0.01rad in high probability.

Now an experimental result of autonomous navigation control based on the above work file is shown in Fig. 10. As shown in this figure, the mobile robot for service use successes a fuzzy locomotion, opening a door and getting on an elevator, and completes a command from human being '*Go to the elevator*'.

4. Conclusion

We developed the struvtures of hardware and software of AI control system of a mobile robot for service use in real world applications. The main components of AI control system based on soft computing, fuzzy control, direct human-robot communication and simulation of robot behavior by means of virtual reality generator are described. We propose to use active adaptation block which helps to mobile robot to learn a new actions and scripts based on soft computing as fuzzy neural networks, fuzzy control and genetic algorithms. Mobile robot for service use acquires in this case intelligent behavior and flexibility in execution of technological operations.

References.

(1) Ulyanov S.,Litvintseva L.,Takanashi Sh., Yamafuji K., "Cognitive graphics and virtual reality for direct human-robot communication in mobile robot for service use", 6th Intern. Symp. Micro Machine & Human Science, Nagoya, 241-246,1995 .

(2) Zhakharov V.N., Litvintseva L.V., Ulyanov S.V. , " Virtual medium for control system design of robot for service use "(in Russian), Izv.RAS , Theory and Control System, No.3, 103-110, 1996.

(3) Tanaka T., Ohwi J.,Litvintseva L.V., Yamafuji K. and Ulyanov S.V. , "Intelligent control of a mobile robot for service use in office buildings and its soft computing algorithms". Journal of Robotics and Mechatronics, Vol.8, No. 6, 1-15, 1996.

(4) Ulyanov S.V., Yamafuji K., Miyagawa K., Tanaka T. and Fukuda T. , "Intelligent Fuzzy Motion Control of Mobile Robot for Service Use", Proc. of 1995 IEEE/RSJ Conf. on Intelligent Robots and Systems (IROS'95), Vol. 3, 486-491, 1995.

(5) Litvintseva L.V., Ulyanov S.V., Tanaka T., Ohwi J. and Yamafuji K. , "Intelligent Control of Mobile Robot for Service Use"(in Russian), Int. J. of Software and Systems, No. 3, 297-301, 1996.

(6) Tanaka T., Yamafuji K., Miyagawa K. Takahashi H. and Ulyanov S.V. , "Intelligent Locomotion Control System of the Mobile Robot for Service Use", Proc. of Int. Conf. on Mechatronics and Machine Vision in Practice, 107-112, 1995.

(7) Tanaka T., Kojima Y., Ohwi J., Yamafuji K. and Ulyanov S.V. , "Intelligent Control Technology Operations for Robot for Service Uce", Proc. of IEEE-SMC Symp. on Robotics and Cyberntics, 788-792, 1996.

(8) Kandrashina E.Ju., Litvintseva L.V.,Pospelov D.A.," The Spatio-temporal knowledge representation in the Intelligent systems" (in Russian), Nauka Publ.Moscow, 1989.

Fig. 10. An experimental result of autonomous navigation control.