Short communication

Soft Computing 1 (1997) 88–98

Soft computing algorithms for intelligent control of a mobile robot for service use

Part 1: Direct human-robot communications and managing system for cooperative control

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Abstract The arrangement principles and design methodology on soft computing for complex control framework of AI control system are introduced. The basis of this methodology is computer simulation of dynamics for mechanical robotic system with the help of qualitative physics and search for possible solutions by genetic algorithms (GA). New approach for direct human-robot communication with natural language (NL) and cognitive graphics is introduced. 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 are proposed.

Keywords: mobile robot for service use, soft computing, intelligent control, direct human-robot communication

1 Introduction

At present two classes of mobile robots for service use are distinguished, Pellerin (1993), Asami (1994): (1) Class A (Robots to replace human beings at work in dirty, hazardous and/or tedious operations); and (2) Class B (Robots to operate on/or with human beings to alleviate incommodity or to increase comfort/pleasure). Class A includes operations in hazardous or extreme environment (e.g., radioactive environments, high temperatures, underwater, vacuum, harmful gases), fire-fighting, military applications and so on. Class B includes medicine, housework, entertainment and others.

Extensive researches have been conducted in recent years in developed countries for the purpose of fabricating mobile robots for service use of Class A which are capable of moving along horizontal, inclined or vertical surfaces. Such robots must be capable of overcoming or avoiding obstacles encountered on their paths, or returning to the required initial (start) position, set up to execute the required industrial operations and to perform such execution. Such robots and robotic complexes are needed because of increasing demands on industrial operations, accident and emergency conditions, and conditions that are hazardous or difficult for human operator. Mobile robots for service use for solving the tasks of Class A have been developed in papers, Ulyanov et al. (1995).

The first mobile robot for service use for solving the tasks of Class B was investigated in papers, Yamafuji et al. (1992), Ishikawa et al. (1994), and intelligent control system with soft computing was developed in papers, Ishikawa et al. (1994), Ulyanov et al. (1995), Tanaka et al. (1995), Ohwi et al. (1995). In this paper the intelligent robot for service use (as Class B) in buildings, especially in office buildings are developed. Figure 1 shows an experimental prototype of the mobile robot for service use. This robot is power-wheeled steering type which is achieved by two driving wheels and a caster with passive suspension for stable locomotion. Thirteen ultrasonic (US) sensors, nine infrared (IR) sensors, a five degree-of-freedom (DOF) manipulator with a three finger hand and a CCD camera are equipped on the robot for conducting tasks and works in buildings including human being, opening door and getting on an elevator.

The service robot can be utilized as "a secretary-or helper-robot" by daytime and "robot for security guard or maintenance including cleaning floor" by night in office buildings, Yamafuji et al. (1992), Ishikawa et al. (1994), Ulyanov et al. (1995), Tanaka et al. (1995).

Industrial robots have been proved their usefulness in manufacturing environment and become inevitable tools in advanced production systems. Next generation robots must be installed intelligent control system and work outside of manufacturing environment.

Mobile robots for service use are distinguished from industrial robots by the following faculties: (1) mobility; (2) maneouverability; (3) intelligence levels; (4) operating ease; (5) adaptability and (6) portability.

Created by the popular trends toward higher education levels, shortages in the aging specialized labor market, created by the increasing ages of highly skilled technical personnel, and trends toward replacing manual works by robotized operation in hazardous environment are main factors favoring the market demand for robots for service use. Negative factors affecting the robots for service use market include

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Part of the work (connected with direct human-robot communications) developed by Litvintseva L.V. was supported partially by Russian Fund of Fundamental Research under Grant No. 95-01-007729a. This support is gratefully acknowledged.

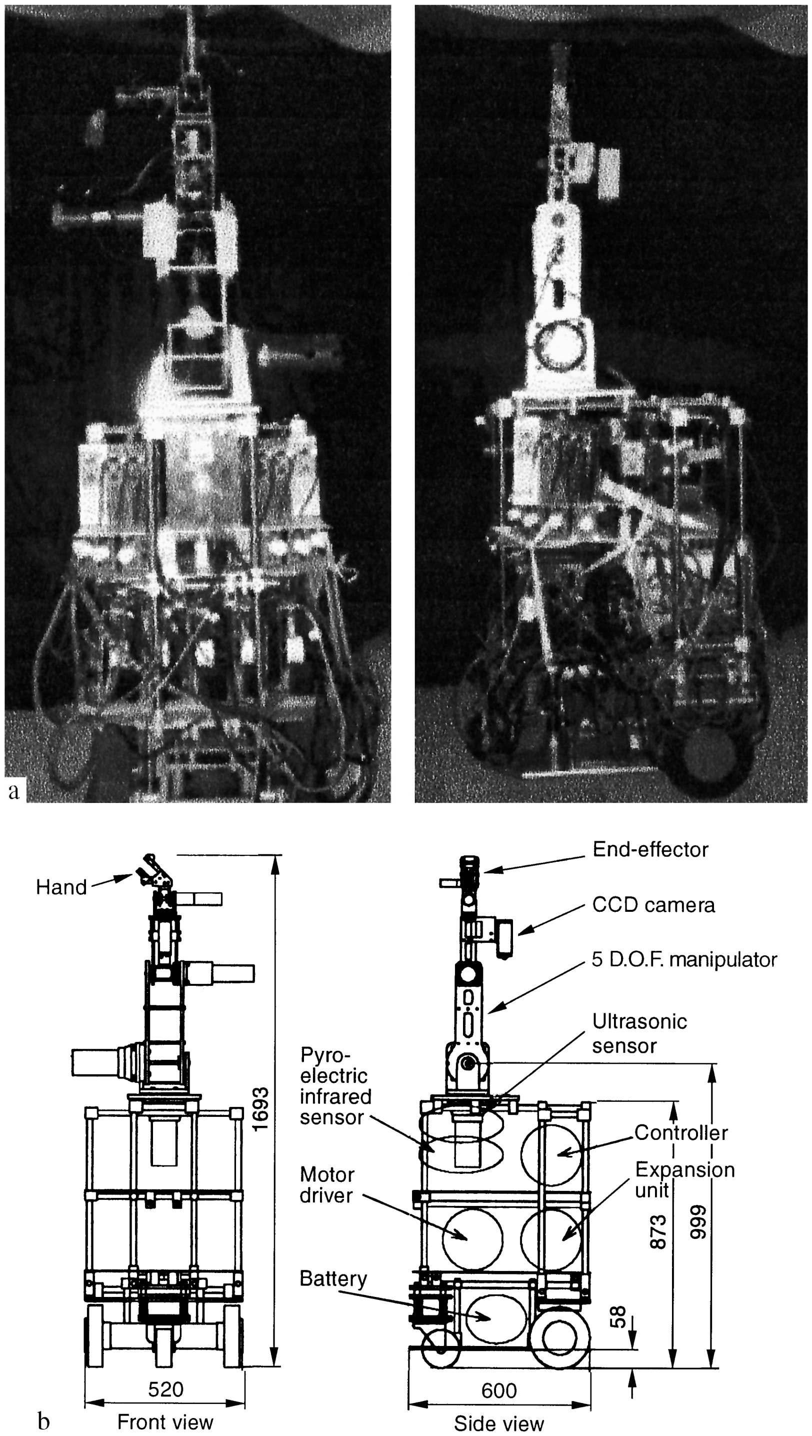

Fig. 1. Developed mobile robot for service use. **a** Picture of the robot **b** View of the robot

insufficiently rapid development of requisite sensors and of their intelligent faculty, and high cost, Asami (1994).

Further development of this new field in robotic engineering permit, to compensate for negative factors has required research aimed at improving robot mobility and maneouverability, as well as robot intelligence (sensing, learning and judging function) and expanding technological capabilities and effective fields of application.

This paper describe a new approach to intelligent control system design and have two parts.

In Part 1, a new forms of direct human-robot communications (including emotion, instinct and intuition) and an autonomous locomotion control system are developed. Figure 2 shows the structure of this intelligent control system. We will consider as the first step one line in this scheme: direct human-robot communications based on NL and construct the simulation system of spatial scenes and robot behavior in virtual reality (VR). The structure of this system is shown on Fig. 3. We explain also the managing system which controls cooperatively three sub-systems of the service robot, as the

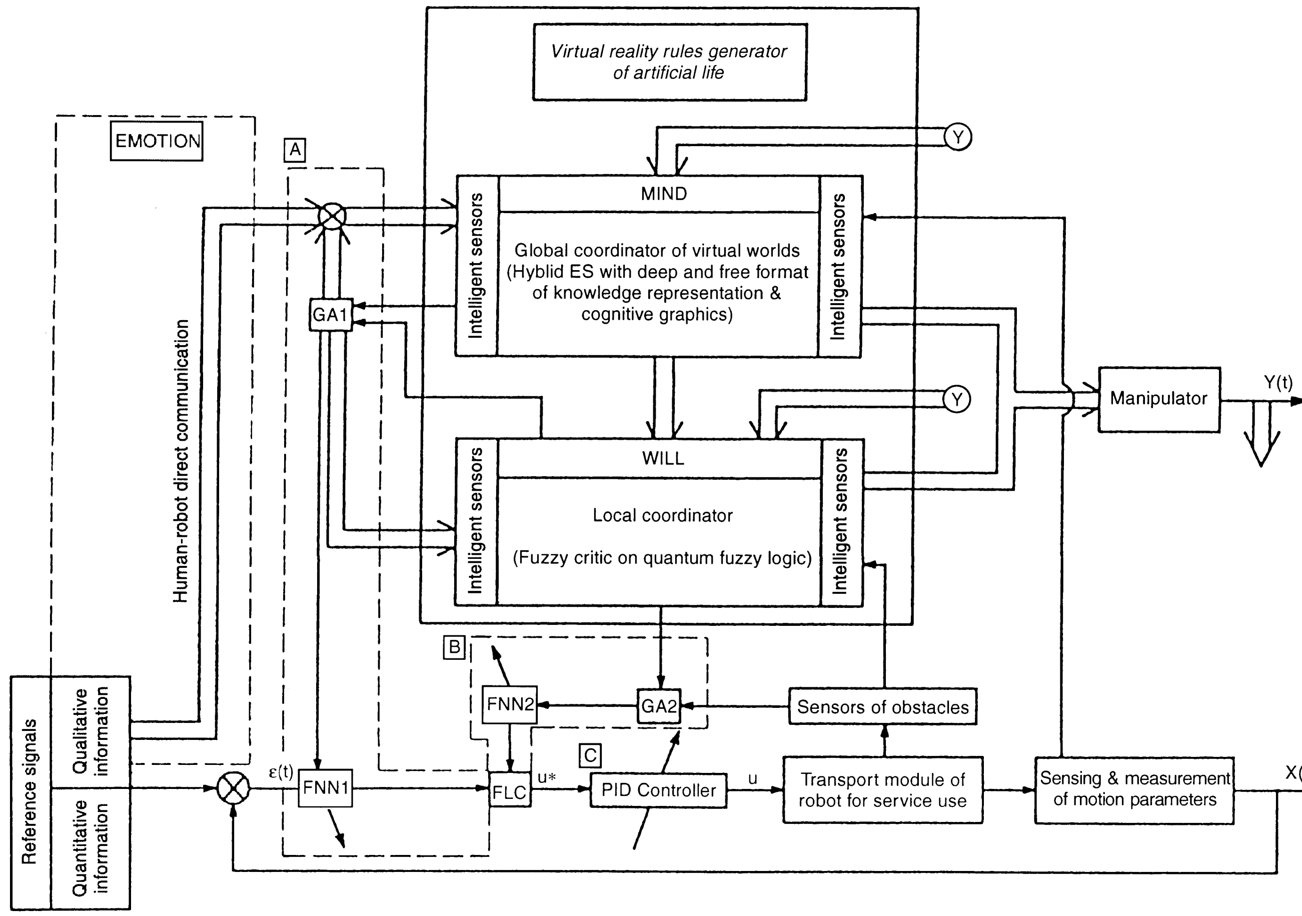

Fig. 2. Structure of AI control system with distributed knowledge representation (on control signal levels). **a** Intelligent control "in large" **b** Intelligent control "in small" **c** Control on executive level

locomotion system, the handling system for a mobile manipulator and the image processing system as human vision system. This managing system is based on GA and HN map method. In Part 2, three sub-systems will be described in detail. Experimental results on the developed robot show that the proposed methods are very useful for autonomous locomotion control of the robot.

2
Direct human-robot communications with behavior simulation system

In this part we consider the use of NL and cognitive graphics, Litvintseva (1993), for condition descriptions of robot artificial life and direct human-robot communications for a mobile service robot shown in Fig. 2. The mobile robot for service use works in buildings with different scenes of rooms and moves in unstructured environments in presence of many people and unexpected obstacles. We propose to construct a simulation system for mobile service robot behavior based on cognitive graphics. This system is used for possible world's simulation in the robot artificial life. This allows us to evaluate the control algorithms of real time robot behavior and to reduce difficulties connected with such troubles as robot collisions with obstacles and robot hardware damages.

The mathematical background of robot behavior simulation system is knowledge engineering based on spatio-temporal and action logics, default reasoning, cognitive graphics and soft computing. Here we discuss the main concepts, structure and conceptual model of behavior simulation system for description of artificial life as mobile robot for service use in office buildings.

2.1
Task definition

In accordance with the scheme shown in Fig. 2 consider the line of direct human-robot communication based on NL. We will construct the simulation system of spatial scenes and robot behavior in simulation environment (VR). The output information of this simulation system used in autonomous locomotion system (see Fig. 4) for a global path planning and as command from human being.

Human operator represents the NL-description of artificial life conditions of the mobile robot for service use. This 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 them and so on); 2) The scripts of robotic artificial life (for example, actions as "go to the room";

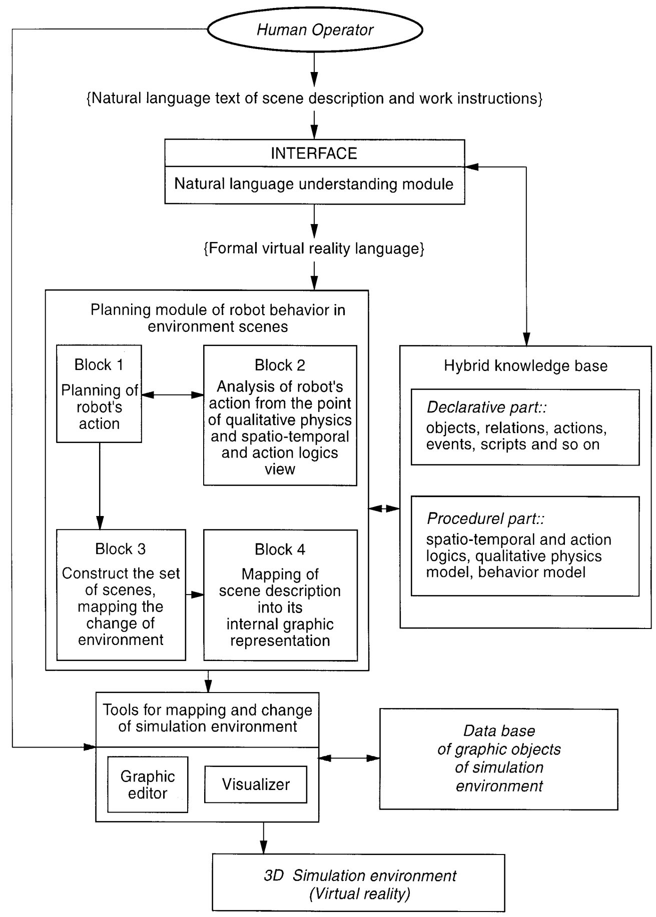

Fig. 3. Structure of robot's behavior simulation system

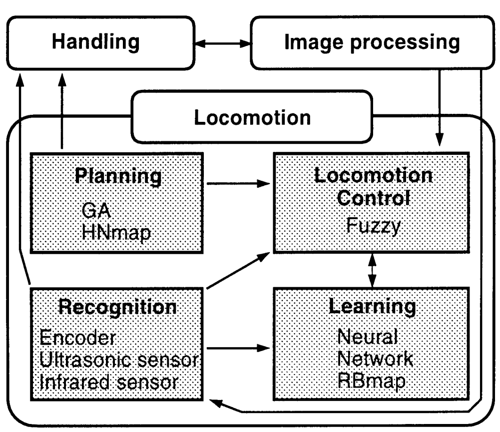

Fig. 4. Proposed autonomous locomotion system

"imagine the room"; "show image of the room"; "open the door"; "grasp the book on the desk" and so on).

We consider the NL-text as human-robot communication input (see Fig. 2) that describes environment situations in space and in time, Ulyanov et al. (1995). The NL-text is transformed into internal representations (IR) of simulation 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.

2.2 Main concepts and structure of simulation system

The robot behavior simulation system structure is represented in Fig. 3. The system consists of the following modules:

1) menu interface with NL-language understanding module (linguistic processor);

2) planning module of robot behavior in the environment scenes with 4 blocks:
– Block 1: the planning of robot action;
– Block 2: the analysis of robot's action from the point of qualitative physics, spatio-temporal and action logics view;
– Block 3: the construction of the set of scenes mapping the environment changes connected with actions:
– Block 4: the mapping of scenes description into IR;

3) Tools for mapping and change of simulation environment scenes including:
–Graphic Editor and Visualizer;

4) Knowledge and Graphic object bases.

The NL-text input describes the 3D spatial scenes (for example, room) with objects and spatial relations between them and contains the work instructions for robot what is needed to do in this 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.

Consider *the structure of the simulation system*.

Menu interface contains the pathways to access the primary modules of the system: "NL-text Input", "Tools for Mapping and Change Scenes" and so on.

The NL-text inputs to linguistic processor realizing its transformation to IR on the formal VR language (VRL) (see below). IR includes the frame copies set such as: objects, subjects, spatial relations, actions, scenes and scripts. For NL-processing the modification of Wood's augmented transition networks method is used. Blocks 1 and 2 on Fig. 3 are used for the realization of the following functions:

– checking whether it is possible to realize the action from qualitative physics point of view;
– construction of action realization plan based on script;
– casual actions or event outcome;
– trajectory construction connected with given action;
– analysis of correctness from the point of spatial logic view for the given scene.

Blocks 3 and 4 are used for:
– object location planning in the current spatial scene;
– construction of internal graphical representation of scene description.

So we have the set $\langle XYZ \rangle$ of object coordinates in the coordinate system connected with spatial scene as the output from Block 4. Then the visual processor (Visualizer) converts this coordinates to an absolute coordinate to be displayed.

The Graphic Editor is used for creating and modification of 3D object images of environment scenes. The example of graphical object representation is shown in Fig. 5. In this case

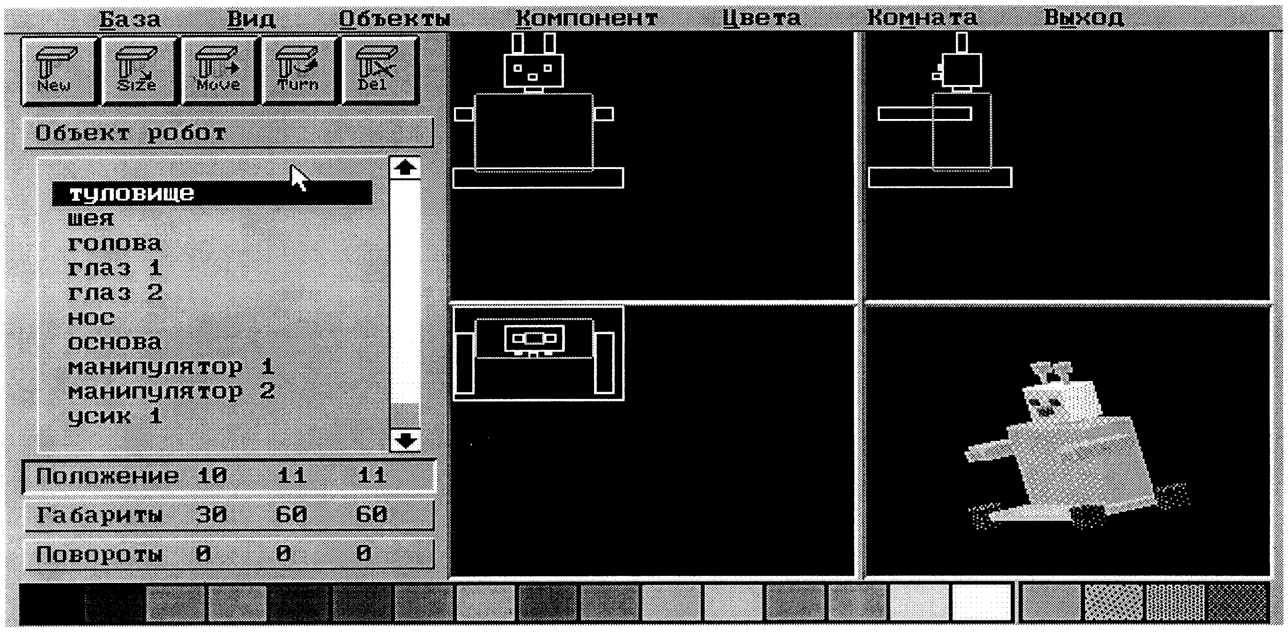

Fig. 5. Example of graphic representation of object obtained by tools of Graphic Editor (4 versions of visualization)

Fig. 5 presents a Russian version of graphical editor[1]. The English version of graphical menu for graphical representation of mobile robot (the left side on Fig. 5) translated as: object-robot; the body (of robot); the head; the neck; the eye 1; the eye 2; the nose; manipulator 1; manipulator 2; the position; the size; the angles, respectively. Here we use the main principle of cognitive graphics for graphic representation of our simulation environment. This is following, Litvintseva (1993); instead of complicated mathematical models of graphic representation of environment objects we use more simple images as a result of knowledge-based mapping. For our task it is important adequate mapping of spatial and dynamic situations to examine the algorithms of rational robot's behavior.

The knowledge base (KB) consists of few knowledge classes. There are a priori knowledge and knowledge acquired in the process of problem solving.

All of *a priori knowledge* can be divided into three classes: 1) *Class A* contains syntactic knowledge about objects, subjects, actions, relations; 2) *Class B* contains knowledge about pseudophysical spatial logic and action logic, which are one of logical deductive systems for a geometrical and physical description of a space and actions, Kandrashina et al. (1989). These logics are used for simulation of spatial scenes and dynamic situation; 3) *Class C* includes knowledge about semantic and pragmatic properties of actions, of objects and spatial relations between them.

Class D contains knowledge acquired in the process of problem solving.

Mixed frames and production rules approach is used for knowledge representation.The frame part of KB describes the objects and their properties, relations and actions. The production part of KB describes the spatial logic axioms and qualitative physics productions.

2.3
The formal language for a simulation of robot behavior in 3D spatial scenes

We will consider the following virtual environment for a mobile robot for service use. This robot works in a complex world like a building with many rooms, floors, corridors, elevators, other robots and so on. In each room there are many objects with different spatial relations. Robot realizes actions connected with objects in the room and change the spatial relations between them. To simulate such environment we develop a formal language for description of environment scenes and its change according to robot's actions named as Virtual Reality Language-VRL. Table 1 and Table 2 show the basic notions, syntax and semantics of VRL respectively.

2.4
The problems of spatio-temporal and action logics design for intelligent decision making and reasoning of the robot for service use

Reasoning about time, space and action is an important aspect of the rational behavior of intelligent systems. Much works have been developed to describe various paradigms for reasoning and an attention is focused on the logic-based theoretical frameworks. Litvintseva (1993), Kandrashina et al. (1989), Ulyanov and Litvintseva (1993).

We developed an approximate reasoning system, based on so called pseudophysical spatio-temporal and actions logics, Kandrashina et al. (1989), Ulyanov and Litvintseva (1993). The name "pseudophysical logic" is explained by the fact that neither real physical and metrical properties of time, space and action nor human perception properties are used in axioms in inference rules. The important factors of this model are:

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[1] The graphic editor is developed by S. Nalitov under Grant No. 95-01-007729a of the Russian Fund of Fundamental Research.

Table 1. Basic temporal, spatial relations and actions in the behavior simulation system of robot for service use

Temporal logic relations	Spatial logic relations	Action logic actions
1) *For temporal points and instant events* *Nonmetric order relations*: – to be earlier; – to be later; – to be simultaneously; *Metric relations*: – to be earlier on N unit on the time scale L; – to be later on N unit on the time scale L; *Fuzzy relations*: – to be approximately simultaneous; – to be substantially earlier; – to be substantially later; – to be not so substantially earlier; – to be not so substantially later; 2) *For temporal interval and events*: All mentioned above relations plus 7 different types of interval intersection; 3) *For actions*: – at time t (or approximately) being action d; – at time t (or approximately) finish action d; – after action d1 (or interval T1) begin action d2; – before action d1 (or interval T1) begin d2; – immediately after action d1; (or interval T1) begin action d2; – begin action d1 simultaneously with action d2; – while action (or event) d1 make action d2; – after each *N* unit on scale L during T interval make action d.	1) *Relative position relations* *Nonmetric*: – to be inside; – to be outside; – to be on; – to be under, over; – to be left, right; – to be in front, behind; – to be between; – to be left (right) and behind (in front); *Metric*: – to be by the angle A; 2) *Spatial proximity relations* *Nonmetric fuzzy relations*: – to contact; – to be closely; – to be very closely; – to be near; – to be far; – to be very far; – to be not far and not closely; *Metric and fuzzy relations*: – to be in the distance of N unit on scale A from (to); – to be in the distance of approximately N unit on scale A from (to); 3) *Fuzzy location relations*: – to be in the center of; – to be in the left (right) back (front) angle of; – to be in the top (bottom) of; 4) *Other relations*: – to have size (small, middle, big, not small, not big and so on); – to have the point of support.	3) *Types of moving*: – to move itself with different types of velocity (quickly, slowly); – to move itself into localization; – to go from point A to point B; – to go nearly to an object; – to go to the left, right, forward, back (according with the current direction of moving) on some (fuzzy) distance; – to change velocity of moving (including stop); – to move itself by the elevator; 2) *Actions with objects*: – to grasp an object (with different types of grasping); – to hold an object; – to put an object at point P; – to put one object on (into, under, from left, from right and so on) another object; – to take the object; – to bring the object; 3) *Force actions*: – to exert force to an object; – to push on the object; – to throw an object; – to turn an object 4) *Other actions*: – to open a door; – to close a door; – wait (event).

1) some reasoning is connected with time scales; 2) there are a few component connected with each other; 3) this is the logic of relations; 4) some component of logic dealing with dynamic situations are nonmonotonic logical systems.

For behavior simulation of the intelligent robot for service use we modify the logics developed in works, Litvintseva (1993), Kandrashina et al. (1989). The examples of experiments showed the effectiveness and adequacy of proposed logics to given task. Example of axioms of this logics are shown in the Table 2.

2.5
Example of soft computing for intelligent position control of mobile robot in simulation behavior system

Consider the rules of soft computing of object coordinates according to fuzzy spatial relations used in the algorithm of Block 4.

We describe the spatial relations between two objects as spatial relations between its basic points. The distance (L_{AB}) between two objects (A and B) connected with fuzzy spatial relation (R) is the function of following parameters:

$$L_{AB} = F(R, L_A, L_B, L_{scene}),$$

where L_A, L_B and L_{scene} are the sizes of object A, object B and scene respectively. For spatial proximity relations we developed following rules for computing L_{AB}:

$$L_{AB} = \begin{cases} K_{closeness}(L_{scene} - L_A - L_B), & L_A \simeq L_B \\ (K_{closeness} + L_A/L_B)(L_{scene} - L_A - L_B), & L_A \gg L_B. \end{cases}$$

Here $K_{closeness}$ is the maximal value of membership function on scale u: $K_{closeness} = \max_u \mu_{r_i}(u)$, where u is the universal linguistic scale of distance.

The rules of computing the basic point coordinates for relative position and fuzzy location relations are also developed, Litvintseva (1993).

2.6
Example of simulation

Let us examine the following task. By the direct human-robot communication line of NL robot received the following

Table 2. The virtual reality language for task of robot behavior simulation

Alphabet	Syntax	Semantics
Alphabet consists of the following sets: Basic notions-set Q including following sets: $\{O_k\}$-objects; $\{A_k\}$- actors (robots); $\{T_k\}$- times; $\{P_k\}$- 3D points; $\{L_k\}$- spatial localizations; $\{SC_k\}$-scripts; $\{S_k\}$-3D scenes; $\{EE_k\}$-external influences and events; The set RR of relations including the following sets: $\{SR_k\}$-spatial relations; $\{CR_k\}$-causal relations; $\{TRk\}$-temporal relations $\{ACT_k\}$-actions; $\{ACTR_k\}$-relations for action descriptions; R_{value}-special relation describing the noncorrectness of the scene from the point of given logics model view.	Following rules for well formed formulas (WFF): 1) If $x \in Q$, $y \in Q$, $R \in [RR]$, then (xRy) is WFF. 2) If F-WFF, then $\forall tF$, $\forall sF$, $\exists tF$, $\exists sF$-WFF; 3) If F-WFF, then $\exists (t_1 \dots t_n)$ F, $\exists (s_1 \dots s_n)$ F, $\forall (t_1 \dots t_n)$ F, $\forall (s_1 \dots s_n)$F-WFF; 4) $\langle s, t \rangle$-WFF, $\langle s, t \rangle \Rightarrow \langle s_1, t_1 \rangle$ – WFF, $\langle s, t \rangle \Rightarrow \langle s_1, t_1 \rangle \dots \langle s_n, t_n \rangle$ –WFF, where " $\Rightarrow$ " is the operator of scene change; 5) If F-WFF, then $\langle s, t \rangle F$ – WFF; 6) If F_1, F_2 – WFF, then F_1 & F_2 – WFF; 7) There is no other rules.	The following axioms (examples): 1) $\langle s, t \rangle d + \exists (t_1 \dots t_k)$ & $\exists (s_1 \dots s_k) \langle s, t \rangle \Rightarrow \langle s_1, t_1 \rangle \Rightarrow \dots \Rightarrow \langle s_k, t_k \rangle$; 2) $\langle s, t \rangle (d_1 R d_2) \rightarrow \exists s_k \exists t_k \langle s, t \rangle d_1$ & $\langle s_k, t_k \rangle d_2$, where R-"to be later", $d_1, d_2 \in \{ACT_k\}$; 3) $(O_1 R O_2) \rightarrow (O_2 R_1 O_3)$, where $O_1, O_2, O_3 \in \{O_k\}$, R- "to be on", R_1-"to be the point of support"; 4) $\langle s, t \rangle (O_1 R_1 O_2)$ & $(O_1 RL)$ & $(O_2 RS) + (s R_{value} F)$, where R_1-" to be in", R- "to have size" L, S-the linguistic value of size (L- "large", S-"small"); 5) $(d_1 R_1 a_1)$ & $(d_1 R_2 O_1) \rightarrow \exists t, \exists s\ (a_1 R_{near} O_1)$, where $R_1, R_2 \in \{ACTR_k\}$ and R_1-to be the actor of action, R_2-to be the object of action; R_{near}–"to be near to the object".

NL-input: "The room number 117 is located at the second floor of the building. The desk is in the center of this room, the chair is on the left side of the desk. The chair is near the desk. The lamp is on the desk. Go to the room, take this lamp and put it on the wardrobe". Using cognitive graphic block, robot may be constructed the graphic representation of described room (that may be considered as global map of this room). The NL-input is presented by linguistic processor

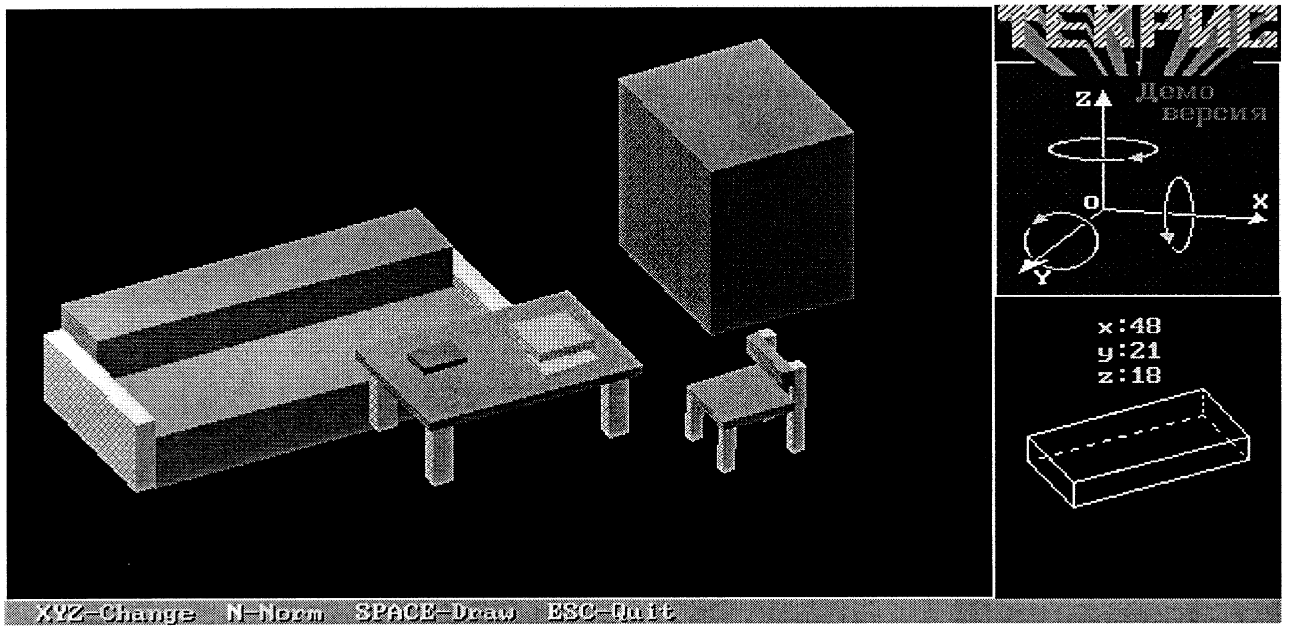

Fig. 6. Example of 3D visualization of static scene (described by the text 1). Different points of view are obtained by the change of (x, y, z)-axises

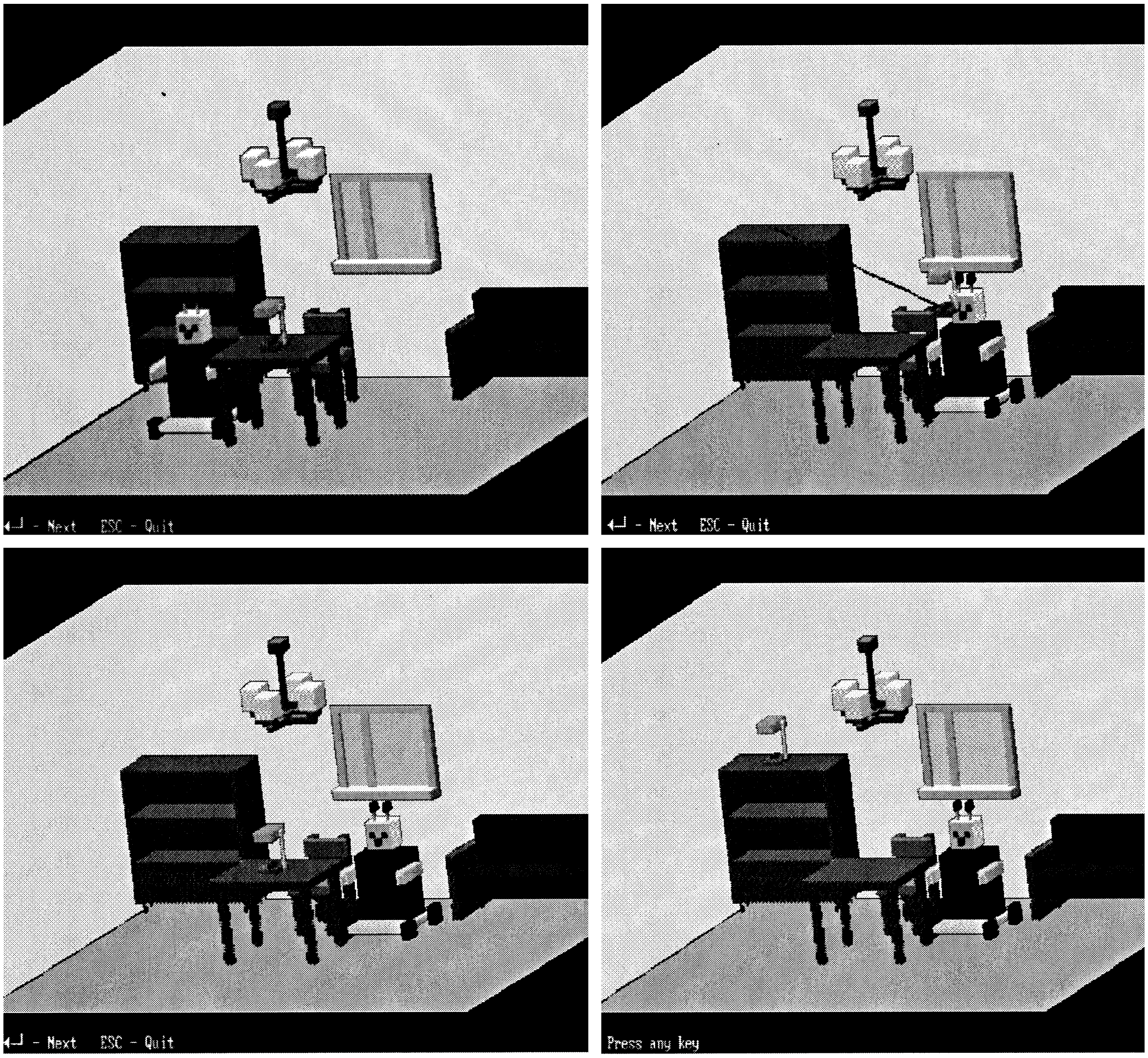

Fig. 7. Example of 3D visualization of dynamic scene (described by the text 2)

into IR on VRL. Two processes are connected with WFF formulas of VRL: the analysis and construction of set of VR-scenes corresponding to the input; the graphic representation of this VR-scenes. These tasks are realized by the above mentioned modules of system. For actions some algorithms for simulation and visualization of this actions have been developed. We use the "step by step" method, in which consider a set of spatial points characterizing the phases of realizing of current action are considered. For example, for action "take the object" the following set of scenes are visualized: the initial scene; the navigation of robot in this scene needed for given action; the scene in which the robot is near the object; and finally the scene in which the robot has this object in your manipulator.

The results of computer simulation of spatial room scenes and robotic actions in the VR of room are shown in the Fig. 6 and Fig. 7, respectively.

Figure 6 shows the 3D graphical representation of NL-description of room as following (*text 1*): "The desk is in the center of room. The book and the lamp is on the desk. A sofa is beside the desk and near it. The chair is located to the right side of the desk and not far from it. The wardrobe is on the right side of the chair."

Figure 7 shows the 3D graphical representation of dynamic scene described by the NL (*text 2*): "The desk is in the center of the room. The lamp is on the desk. Sofa is beside the desk and not far from it. The chair is beside the desk and close to it. The wardrobe is to the left from the chair. Robot stays left from the desk and near it. Robot takes the lamp and puts it across on the wardrobe". In this case a daylight bulb and window in the room is described in terms of default logic.

Such simulation system allows us to examine and correct the different algorithms of task level planning and navigation of the robot for service use. If developed algorithms are adequate for our tasks and goals, the modules of robot action planning and direct human-robot communication can be realized in real environment.

The output information of simulation system is input for managing control locomotion system of second level (see Fig. 2). The structure shown in Fig. 4 presents main modules of autonomous locomotion control system. Consider in detail the main modules of structure in Fig. 4.

3 Managing system for cooperative control

3.1 Main concept of system structure

It is necessary in real environment to control cooperatively and smoothly each robot's sub-systems, as locomotion, handling and image processing system (see Fig. 4). The managing system is constructed up on sub-systems. This system makes the robot to acquire the following abilities.

(1) The robot can understand the command of simulation system from human being on NL; (2) It can control a sub-system according to given commands; (3) It can control one sub-system according to other sub-systems; (4) It can declare the robot's will to human being or the other robot.

In this paper, an intention function which has the preceding capacities (1) and (2) is constructed as a fundamental managing system. Under this function the autonomous control of sub-systems (as robot's mind on Fig. 2) is planned according to given command by using the method of man-robot-interface. In short, a scheduling of each sub-systems is conducted by this system.

3.2 Scheduling

In the previous papers, Ishikawa et al. (1994), Ulyanov et al. (1995), Tanaka et al. (1995), the working-plan function aimed at giving efficient and correct path planning introduced by using Distributed GA (DGA) and HN-map method. However, when the robot's tasks and works came to be more complicated, it is difficult to make efficient path planning in real time. In this DGA a gene was a node in the genetic operation.

In this paper, we use the DGA in which a gene is a distributed area in HN-map and the planned path can be written in one dimension matrix of areas. Thus it is needed to solve this problem more efficiently that we achieve real time control.

Meanwhile, in the robot's locomotion, there are one target point and one aimed task or work in every area. For example, in a case of moving from room to corridor, the robot must go to front of a door and then open a door. And for going to another floor, it has to go to front of an elevator and push a button and then get on.

So HN-map, Ishikawa et al. (1994), Ulyanov et al. (1995), Tanaka et al. (1995), can be used in this scheduling system.

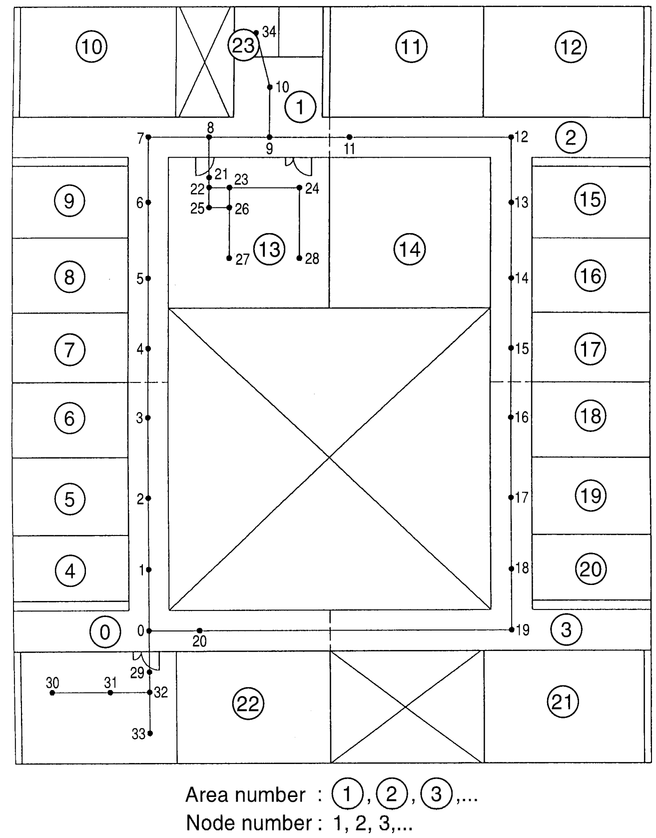

Fig. 8. Hierarchical node map on a floor of a building

This map has a hierarchy of nodes where handling or image processing system has to be controlled. Using the hierarchical map in control system, area-information of HN-map is possible to decide a target point and a task or work on every planned area. Then autonomous scheduling of the service robot can be conducted by means of this method.

3.3 Work file

A planned scheduling data by the proposed method must be changed to recognizeable information as *Work File*. This file is written as follows,

MOVE COMMAND : WORK COMMAND : AREA
: : : : :

- ○ MOVE COMMAND : A command to Locomotion system, a start and a target node;
- ○ WORK COMMAND : A command to Handling and Image-processing system;
- ○ AREA : Locomotion area.

In this paper, there are two command. One is "two Move Command" and another is "six Work Command".

- ○ Move command
  - ◇ GOTO–P1–P2: Go from node P1 to node P2 with fuzzy locomotion;
  - ◇ WAIT–P1–P2: Stay at node P1.
- ○ Work Command
  - ◇ MOVE-TRGT: Go to the target node;

Fig. 9. Experimental result of antonomous navigation in office building

◇ PULL-DOOR : Detect a door knob and pull it;
◇ PUSH-DOOR : Detect a door knob and push it;
◇ GETON-ELV : Detect and push an elevator button, and get on;
◇ OPERA-ELV : Operate an elevator and recognize achieving to another floor to get down on;
◇ GETOF-ELV : Get off an elevator.

3.4 Experimental result

In order to test the effectiveness of the proposed managing system an experiment is conducted using HN-map made by measuring a real environment as shown in Fig. 8. In this experiment, the robot position is decided from the scheme based on simulation system and firstly node is set. It is given the following command by using man-robot-interface: "Go to node 34 (elevator)". The planned area is shown in [13–1–23] And the following Work File is obtained by using scheduling function:

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

Figure 9 is a experimental result of autonomous navigation control on the developed robot in office building. This figure shows that the robot can move continuously from a room (node 26) to an elevator (node 34) by using this Work File with intelligent control for avoidance of obstacle and execution of technology operation as opening of a room door and getting on an elevator.

On this experimental result, it is shown that the proposed managing system is useful for the intelligent robot system.

4 Conclusion

In part 1 of paper, 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 were proposed. The main ideas, structure, simulation method and example of behavior simulation system of mobile robot for service use in VR based on NL and cognitive graphics were discussed. Mobile robot for service use acquires in this case intelligent behavior and flexibility in execution of technological operations and avoidance of obstacles in office buildings in co-existence with human being.

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