Semantics-Based Control of the Group of Intelligent Robots

Ivan Podmazov
Laboratory of Robotic Systems
United Institute of Informatics Problems of the NAS of Belarus
Minsk, Belarus
podmazov@gmail.com

***Abstract*—In this paper we offer architecture of a software part of an intelligent robot group designed for work in complex dynamic enviroment conditions. The approach is based on application of the Open Semantic Technology for Intelligent Systems (OSTIS). That will allow to accelerate the intelligent control system development process, at the same time preserving its capability and quality thanks to the advantages of the architecture and the development sequence. Our goal is to construct a group of robots with limited cognitive abilities that are able to operate knowledge in formalized form, to deduce new knowledge and also to have an access to existing external intelligent systems and knowledge bases. The intelligent robot group software is built hierarchically: overlying components are implemented on the basis of underlying ones. The hierarchy includes three abstraction layers: programming language extension level, intelligent system level, robot group control level. It seems that control system built in accordance with the suggested architecture possesses the qualities of versatility and extensibility, and that will provide the breadth of supported functionality.**

***Keywords*—intelligent system, robotics, robot group, control system, semantic technology, OSTIS**

I. Introduction

Agent group control in a complex unpredictable environment is an actively explored and developing field of artificial intelligence. A concept of agent in the group artificial intellect as an independent science is abstract since the greatest interest of the latter is the properties related to interactions and not the properties of active units. Nevertheless, individual properties are important and can influence significantly on the efficiency of the whole group. It is known that increase in agent's cognitive abilities leads to complication and enrichment of behavioral diversity improving by that its adaptive capability in current conditions of rapidly changing environment [1], [2]. For instance, in nature species possessing more developed brain have an evolutional advantage and take a higher place in the food chain. Eventually, when a species gets the ability to think i.e. to find hidden, directly unrecognizable regularities of the world's phenomena, its possibilities come to a new level [3]. The most obvious example is homo sapiens, a species not distinguished by physical strength and dexterity learned to subdue the forces of nature and to use them for own purposes through its intellect, and thereby became dominant in the scales of the Earth's biosphere. In practical applications, real control objects are identified with the agents. Particularly, in robotics such objects are group robots.

Invention of artificial "servants" for the sake of elimination of the need for manual labor is the one of the human's oldest dreams. The robotization and automatization processes originate from the earlier and more common process of construction of artificial tools with the required properties. This process have led to the appearance of the devices that "boost" the human body physical qualities, allowing to carry out working operations faster and more precisely. Total rejection of the human involvement in production and service cycle is simultaneously the goal and the outcome of automatization and robotization [4].

Works have been started to create "thinking" devices that could not just become a high-grade substitute of a human workers, but also to be networked into much more effective and powerful systems, though the significant difficulties showed up. It turned out that only the formalizable, simply algorythmized procedures can be easily automated, while the automatization of unformalizable procedures face some difficult problems. In despite of series of considerable and useful results obtained in this scope, a human is without a rival in solving creative and other non-formalizable problems at the moment. [5], [6]. Thereby presently the basic practical robotics problem is to construct collectives of robots with limited, but sufficient cognitive abilities for specific purposes such as formalized knowledge processing (including inference of new knowledge) and access to vast array of information accumulated by humanity etc.

II. Robot group architecture

This article reviews the problem of construction of a versatile intelligent control system for a group of intelligent robots acting in complex dynamic environment. Schematic representation of the group architecture is shown in the fig. 1.

The group consists of N in general different robots, each of them contains:

- general-purpose computing unit (controller) – blocks RS, KB, CS;
- wireless communication module – block T;
- sensor set (camera, microphone, magnetometer, obstacle sensors etc.) – block S;
- actuator set (chassis, manipulators etc.) – block A.

Except robots, the group includes a server used for centralized synchronization of the knowledge bases and for inter-

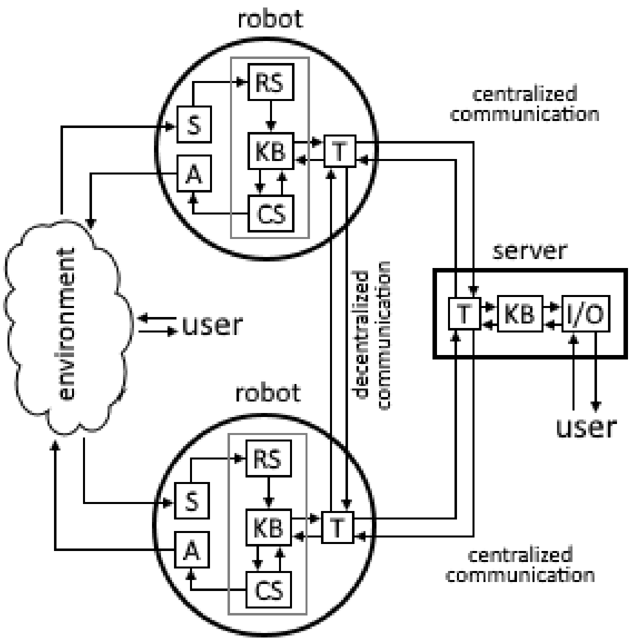

Figure 1. Scheme of a group (collective) of intelligent robots (S = sensors, RS = recognition system, KB = knowledge base, CS = control system, A = actuators, T = transmitter, I/O = input-output system).

action with the user. Interaction with the user is carried out through the intelligent input-output system (block I/O).

The robots and server run software with all functionality required for semantic calculations and processing of knowledge in formalized form. Each robot is able to recognize events and contexts in an input data stream (from sensors, block S) and generate its semantic description in a certain universal fact-presentation language (by means of the recognition system, block RS). Besides, the robot accepts individual and group commands which are extracted from sensor data the same way. Newly generated descriptions are put in a local knowledge base (block KB), maintaining its consistency. In fact, this base represents a semantic map of environment that can be used to complete the task whether by a robot itself or by some group subset. In order to synchronize the base, its fragments are distributed within the group on request – directly or through the server containing the global database (block KB). Robot control is carried out directly by the intelligent control system (block CS), which does the semantic analysis of the current situation and makes a decision on further actions in obedience to the user input (hereafter carried out by actuators, block A).

To give an example of the use of such a group, we consider the problem of mapping of premises performed by a group of robots that are able to answer questions like:

- how many floors there are in the building, how many rooms there are on the floor, how many doors there are in the room etc.;
- how many robots in the group are active, where are they located;
- what does a particular robot see or hear, etc.;

as well as are able to carry out assignments like:

- to find a certain object or person (to set location);
- to get, to deliver an object or to escort a person to a given point;
- to identify/modify an object state (for example, to find out if all the doors on the floor are closed) etc.

Besides, the input may be supplied vocally to all group members. Each request requires recognition of a complex verbal command, knowledge database operations, semantic calculations and interaction with the other robots. The Laboratory of Robotic Systems of the United Institute of Informatics Problems has already got some practical results in the mentioned direction: a computer vision system for calculating a point of perspective on picture frame received from onboard camera has been designed. That lets a robot to move on a sidewalk, in the corridors of the building and even to find the right door [7].

Thus, the problem of construction of a control system for a group of robots that corresponds to the specified description, involves the solution of the following subtasks:

1) implementation of the recognition system (block RS);
2) developing of the system of knowledge processing, synchronization and storage (blocks KB, CS);
3) developing of the "human-robot" interface that supports the use of anthropomorphic language (block I/O).

It is supposed that each of them can be solved by using and integration of existing intelligent and other program systems (which will require implementation of specialized program interfaces).

III. Software architecture

The intelligent robot software is built in accordance with the principles of the OSTIS (Open Semantic Technology for Intelligent Systems) [8]. The technology is called "semantic" since its essence is in applying semantic networks of special unified kind for the representation of any structured information and constructing of special information processing systems. Thereby a number of problems is planned to be solved, among which one can mention simplification of the integration of different information representation models, shortening of intelligent system development terms and complexity as well as improvement of its quality.

According to the OSTIS principles, the intelligent robot group software of the considered type is supposed to be hierarchical as shown on the fig. 2.

The hierarchy consists of three levels of abstraction:

1) programming language extension level;
2) intelligent system level;
3) robot group control level.

First two levels are universal and are present in one or another form in every intelligent system implemented in accordance with the OSTIS principles. The third level is a quintessence of intelligent system and corresponds some

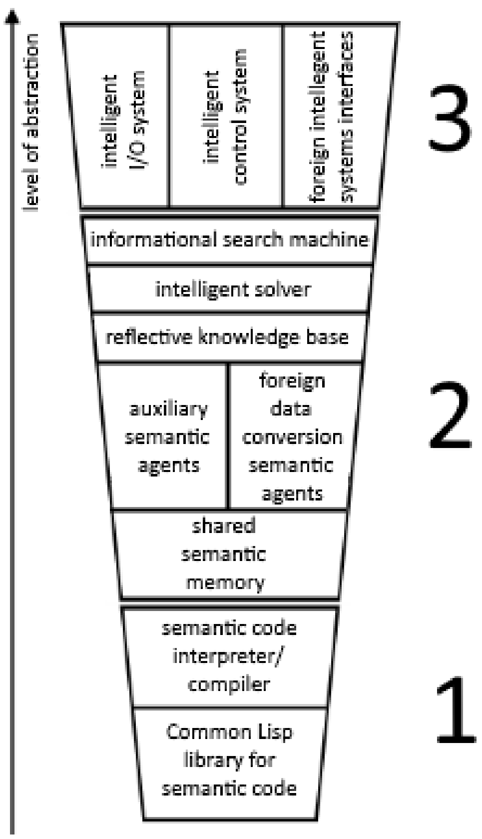

Figure 2. Structure of the robot group software.

particular problem, contains means and description of the considered problem solution.

The first abstraction level contains means that expand the programming language features concerning semantic networks processing. The basis of this is the library implementing a domain-specific language (DSL) in which all overlying layers are written. It is known [9] that one of the most convenient languages for DSL implementation is Common Lisp. Due to the powerful macro system allowing to transform language syntax drastically, introducing by that the means that make the code systematic, brief and laconic, speed and quality of development increase at times in comparison with popular general-purpose programming languages [10]. Above the specified library lies a meta application intended for semantic code execution by means of interpretation or compilation and its subsequent launch. In both cases the output is a proper specialized program containing instructions for semantic agents of a certain type that is executed as a separate process in an operating system.

The second level of abstraction represents an implementation of the intelligent system basis – sc-machine, supplemented by a knowledge base that contains information about the system organization and usage. The fig. 3 shows a general scheme of internal organization interactions of the semantic machine.

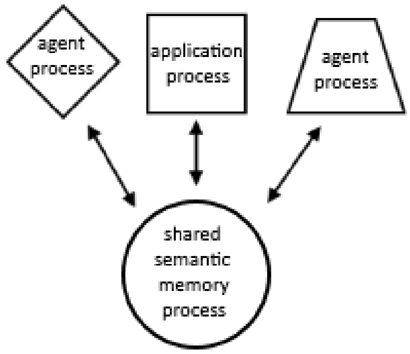

Figure 3. Robot's multiagent system of a semantic machine (sc-machine).

Sc-machine consists of a multiplicity of agents (operating system processes) of different complexity and functionality that interact with the shared semantic memory (which is also a process). All inter-agent interactions are conducted exclusively through the shared memory. High-level intelligent subsystems – intelligent solver, information retrieval machine and user interface core are built on this basis. In order to render interfacing of semantic technology with the outer systems possible, there are agents that perform convertion of semantic networks to external formats and vice versa. The knowledge base which is a part of the second level contains detailed description of the whole system including basic concepts and their interrelation. Besides, the base includes information on rights, access to resources and interaction of all the entities participating in system operation, both program agents and users.

On the third, robot group control level, there is a complex of means that use the previous levels functionality to solve the assigned problem of robot group control. This complex includes an intelligent user interface (which contains server web-interface as well as robot's voice command recognition subsystem), the control system actually and the collection of interfaces for external intelligent and other program systems. The latter is intended to exploit external systems in order to extract missing information that can not be obtained in the system (for example, when a user requests a fact from external sources), as well as to have an impact on them. Intelligent group control system performs parsing of input which is presented as semantic network, calculates the expected behaviour and ensures its accomplishment by outputting the response through the user interface either by sending appropriate signals to actuators which lead to the desired result. As a matter of fact, the control system does not contain any hard-coded parts, since the whole functionality is provided through well-established interaction of underlying subsystems – the information retrieval machine and the prearranged knowledge base.

IV. Elements of semantics-based control

Semantics-based control of the groups of intelligent robots is understood as the transfer of the maximum propotion of computation to an informational search machine and an intelligent solver from of the hard-coded algorithms. Group interaction and control are provided by two factors: the availability of knowledge base synchronization and the possibility to utilize other robots' resources in order to solve the specific robot problem through the support of corresponding terminal elements and rules. Synchronization is the exchange of information between robots. The information presented in the form of a semantic network, the volume and content of which is determined by the interaction graph corresponding to the task (it may be raw/processed sensor data, calculations results, etc). Received information updates the state of the robot and alters its behavior. Deduction of the robot behavior is carried out by informational search machine and intelligent solver on the basis of logic deriving process. This process uses the acquired facts about the state of the environment as well as the prearranged rules of behavior from the knowledge base.

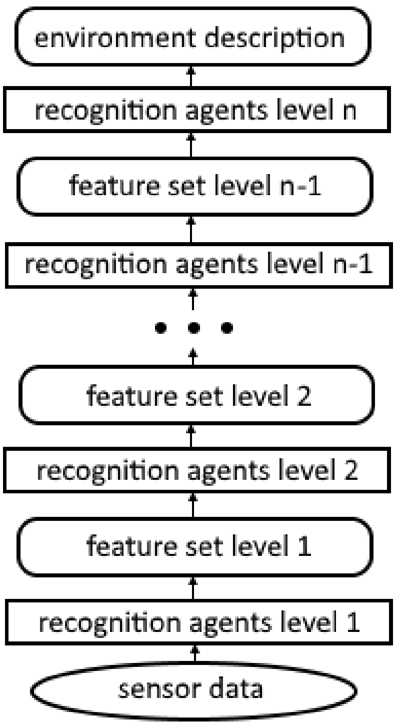

Figure 4. Recognition agents hierarchy and input data conversion sequence.

The specified functionality is implemented through the availability of agents of the following types.

- General-purpose (universal) agents provide functioning of the entire system as a whole, including auxiliary transformations and algorithms that are inherent in any intelligent system built according to OSTIS principles. They also include data representation transformation agents and all agents that are not specific to the robot group control system.
- Agents of recognition of events and patterns in the input data stream, as well as the agents for parsing verbal input form a hierarchical subsystem consisting of several levels. Each next level takes results of the previous level as the input; the first level performs the primary processing of data from the sensors (fig. 4). Such a structure allows to significantly compress the input stream by discarding non-essential information and forming a compact semantic description that can later be transmitted to the rest of the robots and "understood" by them without any additional calculation (example: frame from the on-board camera => number, types, orientation of the objects captured). Combining the descriptions of the environment at different times and from different sources makes it possible to construct a semantic map of the environment.
- Synchronization agents of knowledge bases in the group select, send, receive and integrate semantic information. The mode of operation of this type of agent is not fixed and is also subject to adjustment by the joint activities organizing mechanism for a group of robots.
- Agents for output generation and actuator control, like agents for input data recognition, form a hierarchical system that converts a high-level description of the action decisions made into hardware implementation level commands (for example: "output required" => sound/text, "motion required" => signals fed to the drives).

Simplified algorithm for the operation of a robot in semantics-controlled group is as follows:

1) collect data from sensors and generate their semantic descriptions, add it to the knowledge base;
2) receive semantic information from the other robots and the user and add it to the knowledge base;
3) revise (repeat derivation of description) of the current behavior as a result of the running of informational search machine and intelligent solver over the updated knowledge base;
4) transfer the required semantic information to other robots and the user;
5) execute the accepted behavior.

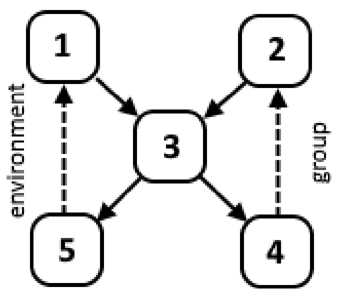

Figure 5. Dependence graph for the robot functioning algorithm (solid arrow – direct internal dependence, dashed arrow – existence of external feedback, feedback channel is noted nearby)

Figure 5 depicts the dependency graph of the algorithm steps. It is understood that the steps are performed asynchronously. It is guaranteed that the integrity of the database and the control system is always maintained and can not be violated by impact on the robot through the provided communication channels.

Thus, the structure of the system is flexible and allows to make changes to it with minimal costs, even in on-line mode. If there are agents that monitor the correctness of the state of the knowledge base, accidentally making an error becomes less likely. On the grounds of the taken architectural solutions, it seems that the intelligent control system for a group of robots has a significant potential regarding expansion the provided functionality.

We suppose that the OSTIS has significant power and is able to offer a solution that could be a leap forward over the existing ones in various fields of computer science. In particular, it can help in improving of intelligent technologies of the group robotics on account of integration with the third-party intelligent technologies.

V. Conclusion

In this paper we offer architecture of a software part of an intelligent robot group designed for work in complex dynamic enviroment conditions. The approach is based on application of the Open Semantic Technology for Intelligent Systems (OSTIS). That will allow to accelerate the intelligent control system development process, at the same time preserving its capability and quality thanks to the advantages of the architecture and the development sequence.

Our goal is to construct a group of robots with limited cognitive abilities that are designed without taking an example from animals or humans, since we desist from attempts of solving non-formalizable problems. The robots must be able to operate knowledge in formalized form, to deduce new knowledge and also to have an access to existing external intelligent systems and knowledge bases.

The considered group consists of a server and a few in general different robots, each of which contains a general-purpose computing unit and wireless communication module that is necessary for network connection, besides sensors and actuators. The server targets two purposes: centralized synchronization of robot knowledge bases and providing a platform on which the user web-interface is run. Besides the server, interaction with user can be directly effected verbally with robots (verbal command/questions – verbal answer).

The intelligent robot group software is built hierarchically: overlying components are implemented on the basis of underlying ones. The hierarchy includes three abstraction layers: programming language extension level, intelligent system level, robot group control level. The first abstraction level contains means that expand the programming language features concerning semantic networks processing: domain-specific language and semantic code interpreter/compiler. The second level of abstraction represents an implementation of the intelligent system basis – sc-machine, supplemented by a knowledge base that contains information about the system organization and usage, as well as intelligent solver and information retrieval machine built on this basis. The third level includes an intelligent user interface, a collection of interfaces for external intelligent and other program systems and actually a robot group control system. On the third, robot group control level, there is a complex of means that use the previous levels functionality to solve the assigned problem of robot group control. The third level includes an intelligent user interface, the control system actually and the collection of interfaces for external intelligent and other program systems.

Semantics-based control of the groups of intelligent robots is understood as the transfer of the maximum propotion of computation to an informational search machine and an intelligent solver from of the hard-coded algorithms. Group interaction and control are provided by two factors: the availability of knowledge base synchronization and the possibility to utilize other robots' resources in order to solve the specific robot problem through the support of corresponding terminal elements and rules.

It seems that control system built in accordance with the suggested architecture possesses the qualities of versatility and extensibility, and that will provide the breadth of supported functionality.

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УПРАВЛЕНИЕ ГРУППОЙ ИНТЕЛЛЕКТУАЛЬНЫХ РОБОТОВ НА ОСНОВЕ СЕМАНТИЧЕСКОЙ ТЕХНОЛОГИИ

Иван Подмазов
Лаборатория робототехнических систем
Объединённый институт проблем информатики НАН Беларуси
Минск, Беларусь
podmazov@gmail.com

В данной статье предлагается архитектура программной части группы интеллектуальных роботов, предназначенной для работы в условиях сложной динамической среды. Подход основывается на применении открытой семантической технологии проектирования интеллектуальных систем (OSTIS). Это позволит ускорить процесс разработки, но при этом не уступить в мощи либо качестве благодаря преимуществам архитектуры и последовательности построения интеллектуальной системы управления группой. Нашей целью является создание группы роботов с ограниченными когнитивными способностями, способных оперировать знаниями, представленными в формализованном виде, выводить новые знания, а также иметь доступ к существующим внешним интеллектуальным системам и базам знаний. Представляется, что система управления, построенная согласно предложенной иерархической архитектуре, будет обладать качествами гибкости и расширяемости, что позволит обеспечить широту поддерживаемого функционала.