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Education on the Basis of Virtual Learning Robotics Laboratory and Group-Controlled Robots

Victor Andreev[a,b,d]*, Sergey Kuvshinov[b], Valentin Pryanichnikov[a,b,c,d], Yury Poduraev[a]

[a] *Moscow State University of Technology "Stankin", Vadkovskiy per. 1, Moscow 127994, Russia,*
[b] *Russian State University for the Humanities, Miusskaya sq. 6, Moscow, GSP-3, 125993, Russia,*
[c] *Institute of Applied Mathematics of the Russian Academy of Sciences, Miusskaya sq. 4, Moscow, 125047, Russia,*
[d] *International Laboratory "Sensorika", Miusskaya sq. 4, Moscow, 125047, Russia*

Abstract

Based on analysis of data flows and functional structure of information – measuring and control systems of mobile robots with supervisory control, proposed a combined approach to designing this systems and multi-camera computer vision. This approach is based on network technologies and our analysis of data flows and suggested functional structure of main types of mobile robots with supervisory control.

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Keywords: mobile robots; operation environment; computer vision; supervisory control; network with mobile nodes

1. Introduction

At present, the world is experiencing a real revolution in the field of robotics. A wide variety of different educational kits have appeared. From the viewpoint of teaching in engineering sciences, a robot is a unique combination of various science and engineering approaches: theoretical and applied mechanics, mechatronics, electrical technology and electronics, computer science and programming, sensorics (processing of different sensor data), network technologies (local area networks), applied mathematics (data processing and analysis), and even biology (bionics) [1].

* Corresponding author: Victor Andreev, Tel.: +7-903-769-7288; fax: +7-499-250-7951.
E-mail address: andreevvipa@yandex.ru

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Mechatronics and robotics are an efficient tool for preparing IT-specialists. Real robots can be easily projected on a person - every student feels expert in this field. Universal computerization, including in the humanitarian field, makes the task of in-depth training in methods of construction of intellectual systems, which constitute one of the basic problems of robotics. Complex tasks in mechatronics generally suggest creative thinking without exclusion or distancing from the most topical problems of modern manufacturing.

The methods of traditional higher education for preparing IT-specialists and computer professionals are limited by lacking experience of students in constructing hardware–software systems that can secure the interaction between the man-machine systems and control of the real objects. The traditional approach is to grant a typical job for a group of students with different variants of tasks: “one student - one option”. Laboratory works are confirmation of the well-known regularities. It does not provide the ability to search for creative solutions, since there is no element of scientific research, and the formalization of the tasks are not reviewed by the student.

Cheap toys with simple construction, such as first variant of *The Lego* series, cannot enable schoolchildren and students to learn the operation of real robotic systems due to their variety and generally limited access (because these mechatronic devices have high costs). This problem can be solved by establishing technology support centers for education (TSCE) with “robotariums” in leading universities, which incorporate the mechatronic systems for different purposes and are produced by different manufacturers. Specialized educational scientific laboratory allow to create conditions for the training of students during the research work. This implies that the laboratory works are settled as a small research project to be conducted for 1 year. A small research project of this kind would involve 12–17 topics for 45–55 students. The results obtained from each topic are generating new research topics for the next group of students. This structure of the educational process can be called "recurrent". Suggested hardware and software structure of teaching and research mobile robot (stands) should be used in laboratory task, which can be performed simultaneously by several students on a single robot.

TSCE centers are only a partial solution to the problem because there are difficulties for users living in remote places to reach the cities where they are located. In addition, not every university is able to organize a laboratory equipped with a variety of modern mechatronic systems. The availability of the Internet and network technologies make it possible to create a network of TSCEs (located in different cities and countries) with robotarium combined into an international distributed interactive virtual laboratory for teaching doctoral students, students, and schoolchildren to creative methods in computer science and production automation [2]. In this case, the equipment purchased in a given TSCE becomes available to all participants of the project.

2. The purpose and ways of creating a virtual robotics laboratory

The main purpose is to create an innovation technology providing teaching conditions for engineers capable of formalizing problems, finding algorithms for their solution (that can be simply used for a wide class of computing problems), automating of production and robotic industry, and having experience of work with mechatronic systems [3, 4].

To achieve this purpose, it is necessary to develop classes of training robots and intelligent mechatronic systems placed in robotarium at the TSCEs of various educational institutions and develop software providing access to robots of any robotarium through dedicated Internet channels (VPN-channels) from any educational organization regardless of its spatial location (city, country, continent). A virtual laboratory created in this way enables remote supervisory control over any of the available mechatronic systems and their dynamic reprogramming. This laboratory combines hardware and software robotic stands into a single network [5].

The construction of such laboratory requires solution of the following problems:

1. Develop a concept and the functional diagram of an international virtual laboratory and a new type of TSCE network because it contains mobile nodes requiring adaptive control of communication quality. One should choose hardware components and determine specification for the parameters of network devices, Internet channels, and computing technologies.
2. Develop web-based software providing remote access (via Internet) to AMUR educational robots in any robotarium [6], provide supervisory control over their actuators [7], obtain the readings of different sensors (including video signals from multiple cameras simultaneously) [8, 9], and dynamically (i.e., in the course

of operation) reprogram their onboard computers taking into account the network delays and non-guaranteed message delivery conditions that are common to Internet channels [2].

3. Develop methods for teaching of mechatronics, theoretical mechanics, electronics, optics, application programming, and general robotics with the use of remote connection to intelligent mechatronic systems (with a controlling computer) that are physically available and designed for different purposes (robots, manipulators, machine tools, etc.) for students of different levels (schoolchildren, students, and doctoral students).
4. Develop a domain-specific language (DSL) and software for the robotarium system to incorporate robots and intelligent mechatronic systems of different vendors (for example, our own AMUR mobile robots and "Robotino" mobile robots and technological stands developed by the Festo group).

3. Control system over a group of special-purpose robots

The conceptual diagram of the virtual laboratory and its software can be used as a basis for the system of control over a group of special-purpose mobile robots (for example, robotic systems of the Ministry for Civil Defense, Emergencies, and Elimination of Consequences of Natural Disasters).

The digital representation of data and the use of network technologies (the units of a mobile robot are incorporated into a local area network with mobile nodes) make it possible to couple both the components of information-measuring and control systems (IMCSs) of individual mobile robots and the IMCSs of multiple mobile robots into a single distributed system. This enables several robots equipped with different tools to operate simultaneously and allows a distributed IMCS to be reconfigurable. The general structure of the system of communications and control over the group of mobile robots is shown in Fig. 1.

The control over the group of mobile robots is organized in the following way:

- centralized (operated by a single center) supervisory control of the group of mobile robots;
- multi-level hierarchical system of formation and exchange of information and control data flows;
- networking-based software.

To proposed management can be provided through the construction of a multi-level robotic control system (RCS). The first level includes self-contained (onboard) IMCSs of robots. The second level is a distributed supervisory IMCS of individual mobile robots (one robot by one operator). The third level involves systems of top-level rules that are controlled and changed by the commander coordinating the work of operators. To this end, the commander must observe the whole scene and receive information directly from all mobile robots engaged (i.e., be a component of the distributed IMCS of the group of mobile robots).

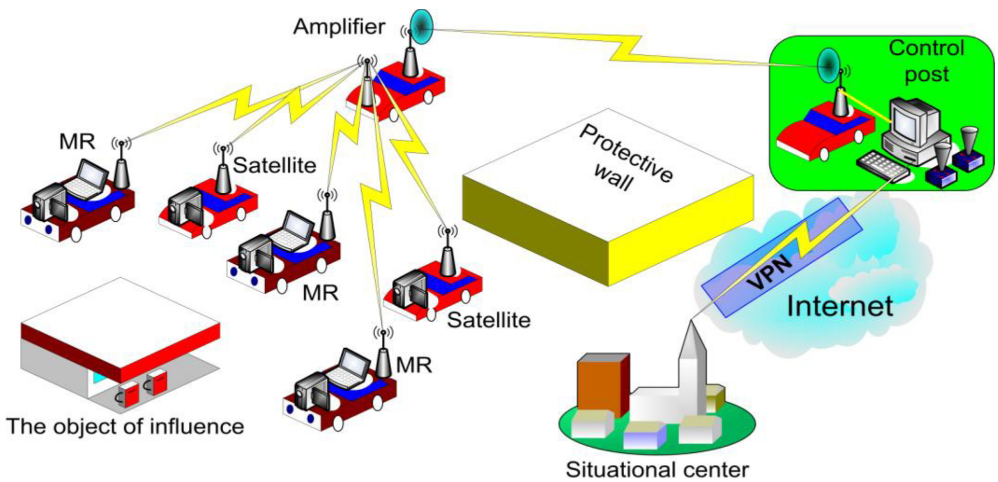

Fig. 1. System of communications and control over the group of mobile robots.

These systems also can be built through Ethernet-technologies. It will suffice that the local area network be connected with a commander PC with a system for displaying data arrivals and having control units, as well as that the hardware system be supplied with appropriate software. The schematic of control over the group of mobile robots shown in Fig. 1 implies the fourth level of control (via the Internet) [10]. In this case, all the information about the operation of the group of robots is sent to "Situation Center", which can be located at almost any distance away from the workplace. It will suffice to have a high-speed Internet channel both in the operation area and at the location of the Situation Center. This channel makes it possible to combine the control center computers, the commander PC (or the entire computer network of the control center), and the network of electronic components of mobile robots into a single network. To ensure that this Internet channel is secure from unauthorized access, a special router that can create a VPN-channel is required at both ends. The development of such systems is a promising line of research serving the interests of Ministry for Civil Defense, Emergencies, and Elimination of Consequences of Natural Disasters.

The International Laboratory "Sensorika" developed systems of supervisory control of mobile robots via the Internet. The methods of control over large distances were optimized using the educational network that combines (through VPN-channels) the laboratories located in the buildings of the International Institute for Advanced Educational Technologies of the Russian State University for Humanities, Keldysh Institute of Applied Mathematics of Russian Academy of Sciences, and the Institute of Automation and Control Processes of the Far Eastern Branch of the Russian Academy of Sciences (in Vladivostok) [11].

It was shown that even a sufficiently fast Internet channel may involve problems limiting the use of this control method in solving critical problems. For example, during the experiments of control from the operation desk in Vladivostok by a mobile robot in Moscow (a distance of around 9000 km), the operator could not guarantee a maneuver by the mobile robot according to the specified trajectory guided by received images and location sensors. The robot sent information about the world around to the operation desk with different delays (approximately 0.3–0.5 s) with periodically lost frames in the video stream. In many situations, the connection with the robot had been completely interrupted for some time interval during the conducted operations. A similar situation was observed also with BROKK-110D and BROKK-330 special-purpose robots, when there are many video streams from the workplace through a Wi-Fi network at the ends of stable signal reception [12].

This problem was resolved by using specific approaches to software development and our own video stream handler. The resulting software allowed the remote control over AMUR educational and research robots with minimum delays as well as the transmission and displaying of multiple video streams simultaneously from cameras installed onboard the robots and on some remote modules. The control over mobile robots via the Internet under conditions of large delays as well as unstable and non-guaranteed delivery of data packets requires compensatory algorithms to increase the control reliability and accuracy. We propose to split the continuous sequence of commands originating from the operation desk into finite sets of commands — short programs executing complete instructions that are interpreted directly by the onboard computer of the mobile robot and immediately executed. In other words, it is necessary to go from remote control to supervisory control. Each of these instructions should be precisely executed regardless of the communication quality of the control channel. The next instruction is sent to the board of the mobile robot only after a notification by the mobile robot that the previous instruction has been completed. In addition, the software of the onboard computer should continuously monitor the readings of sensors installed on the mobile robot and, in the case of critical situations arising from the completion of remote operator commands, stop the execution of this command and inform the operator about the cause of the stop and send the pigtail of sensor readings.

The interpreter used by us made it possible to implement a number of technologies that were previously unavailable:

- Dynamic upgrading of the control program (or its fragment, rather than the entire module as previously), i.e. its change during the system operation.
- Control commands are represented by entire microprograms rather than simple instructions (such as "move forward with a given speed").

Dynamic upgrade enables one to install only an interpreter on the onboard PC and remotely (through communication channels) download to this PC entire programs directly during the operation of the onboard system. This mechanism makes it possible to dynamically change the structure of the onboard software at a level of intelligent control. In this case, the sensor data are transmitted via communication channels to the control panel and analyzed by a powerful computer built into the control panel and by a man. Then, a locomotion problem needed at the given time is formulated with its execution algorithm being generated as a software module. This module is transmitted to the onboard PC, interpreted by it, and executed. This sequence of operations is simply a supervisory control with a dynamically hanging algorithm of the execution of control commands.

If simple instructions are transmitted, the possible interferences or delays in the transmission of control signals can lead to the fact that the robot, for example, picks up the speed with jumps (as the respective control commands arrive), rather than smoothly. If this microprogram is passed directly to the robot board and executed in a microprocessor, the delays can be eliminated and the control smoothened. In this case, a key role is played by the robot sensor readings because the onboard software in critical situations must make provisions of the termination of the microprogram execution.

Supervisory control for the movements of a mobile robot and its actuators increases the role of onboard IMCS and, accordingly, the internal interface. This is due to the fact that the execution of a given instruction should be urgently interrupted in emergency situations, when the operator has produced an incorrect instruction for one reason or other. In the simplest case, this can be an instruction to move straightly for 5 meters, while there would be an obstacle or a break at four meters along this path. The inner control loop must automatically interrupt this instruction and send a respective notification to the operator.

The algorithms (SLAM-type) have been tested and proven to work well in the elaboration of supervisory control systems via the Internet within the “AMUR” project (Fig. 2). Such hardware and software system allows an operator located in one of the laboratories to provide a real-time control over mobile robots in other laboratories.

The video cameras placed onboard the robot and on remote devices supply the operator desk with images from the robot itself and with "side" views. It is critical that images can be obtained from remote modules because this facilitates the work of the operator who is unable to directly observe the actions of mobile robot.

Fig. 2. The classroom (a node of the laboratory network) organized at the Moscow State University of Technology “Stankin”.

The remote modules are equipped with controllable video cameras, which can change their angle and scale by operator commands. At the terminal points of the Internet, the communication of the operator desk with onboard systems and remote modules is served by a radio channel on the basis of using Wi-Fi as a wireless transmission standard [13].

4. Conclusion

The research conducted made it possible to obtain a new technology of software and hardware systems for designing intelligent mobile robots. This technology is based on the development of software and hardware tools for distributed control, simulation, and modeling of intelligent adaptive robots on the basis of software module configuration graphs [10]. The upper level of design is implemented in Python. This technology significantly reduces the implementation time of efficient IMCSs of mobile robots. Thus, in the framework of a single real-time system, we can:

- control sensor devices and robot locomotion,
- simulate the control of mobile robots with manipulators,
- perform mathematical modeling of the control.

This brings significant benefits especially in the construction of a remote supervisory control of mobile robots in emergency situations.

The description of one of the first implementations of mobile robots designed for teaching was published in 1987 (D.E. Okhotsimsky, V.A. Veselov, A.K. Platonov, and V.E. Pryanichnikov) [14].

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