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Organization of Control and Collection of Environmental Information of Service Robots for People with Disabilities

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Abstract: The article describes an approach to creating an effective control of a mobile service robot designed to serve disadvantaged people. A brief overview of the experiments conducted to help people with disabilities with the service robots of the family "AnRI" (Anthropomorphic Robot with Intelligence) developed at the Institute of Robotics at the Bulgarian Academy of Sciences with their design features. The organization of control of service robots with their hierarchical structure is described and the mathematical formalization of its activity is shown. The idea to use the functional characteristics of the Collaborative robots (Cobots) used in industrial production for the purposes of service robotics is shown. Based on the conducted experimental research with robots, an analysis was made in order to increase the manipulativeness and accuracy of work in terms of the tasks they must perform in the process of serving disadvantaged people. The accumulated rich experimental material is systematized in order to derive certain criteria for improving the control of robots.

Keywords: *Collaborative Robots, Control, Service Robots, Special Education*.

1. Introduction

Service robots are designed to work with humans and are universal in their functionality, and their structure can be divided into three main components – working systems, such as a mechanical manipulator system and a global movement system, control system and sensor system for collecting information from the working environment. The practical feasibility of creating such service robots is obvious. Recently, the term "Collaborative Robots" or "Cobots" has also entered the special literature, insofar as these robots operate in close contact with the people served.

The development of robotics allows the use of Collaborative robots (Cobots) in the design of service robots, which are robots intended for direct human robot interaction within a shared space, or where humans and robots are in close proximity. Cobot applications contrast with traditional industrial robot applications in which robots are isolated from human contact [3]. Cobots safety may rely on lightweight construction materials, rounded edges, and inherent limitation of speed and force, or on sensors and software that ensures safe behaviour.

At the present stage of development, the aim is to free man from a large number of monotonous, tiring activities. It should be noted that with the improvement of control systems, robots will be able to perform ever-increasing such activities, reaching a completely independent behaviour with rich human service capabilities.

There are currently two new approaches to organizing robot control. The first approach, also called "Block", is based on the possibility of using libraries with ready-made standard programs, each of which provides a narrowly specialized task, such as installation of elements on a specific surface, implementation of services for people with problems in the home environment and more. These programs suggest the possibility of adaptation to the environment and are ideally adapted to the specifics of the task.

Of considerable interest is the second approach, in which:

- First of all, it is allowed to implement various commands of medium complexity with the help of one or two programs – translators of these commands in the control of the drives of the working bodies of the robot.
- Secondly, it provides the opportunity to learn new actions from the robot, the so-called a "self-learning" procedure that is not pre-programmed by the human operator and using elements of artificial intelligence to recognize situations or sound signals from the environment in a training program.
- Third, based on the combination of these commands using a system of rules and restrictions, it is possible to build complexes of modular programs to perform more complex activities.

The latter condition provides a sufficiently convenient way of communication between the human operator and the robot by using a problem-oriented language, the semantic basis of which is the marked system of commands, and allows to build a high degree of control of the robot and therefore to simplify communication with the human operator on the basis of generalized voice commands – commands executed in high-level language. This also includes the use of human language recognition modules as well as a voice command synthesis module.

2. Organization of Control Structure of AnRI Service Robots

In accordance with the Second approach for the organization of the control of the service robot, the controller performing the functions of management needs to have a multilevel structure with hierarchical connections between the different structural levels. At the heart of the management organization at each level is a single principle, which consists in minimizing some functionalities representing the mismatch between commands, generation from the top level and the magnitude characterizing the current state of the robot and the environment, called “Vector of the situation”.

Within this principle, the given commands represent the elements $\boldsymbol{x}$, $\boldsymbol{y}$ in the general case subsets $\boldsymbol{X^*_y}$ of the set $\boldsymbol{X \subset M_\alpha}$ – metric space. This set can be called “Situation Space” and it characterizes the state of the robot and the environment.

The situation vector $\boldsymbol{x_c}$ represents the value of the operator $\boldsymbol{P}$ in this situation space: $\boldsymbol{x_c = P\ (\upsilon, \lambda)}$, where $\boldsymbol{\upsilon \subset \theta \subset R_n}$ characterizes the state of work and represents a set of coordinates of the degrees of mobility of the working module, where $\boldsymbol{n}$ is the number of degrees of mobility of the working module, and $\boldsymbol{\lambda \subset \Lambda \subset M_\lambda}$ characterizes the state of the environment. $\boldsymbol{M_\lambda}$ – metric space. In a constant medium, obviously

$$\boldsymbol{x_c = P_0\ (\upsilon)}$$

The values of the situation vector are obtained on the basis of the processing of the information by the sensor – measuring system of the robot.

The mismatch function of the robot position and the situation vector is assumed to be expressed as the distance $\boldsymbol{\rho\ (X^*_y, x_c)}$ between the subset $\boldsymbol{X^*_y}$ and the vector $\boldsymbol{x_c}$, where:

$$\boldsymbol{\rho\ (X^*_y, x_c) = \inf \rho\ (x_y, x_c)}$$

$$\boldsymbol{x_y \subset X^*_y}$$

If $\boldsymbol{X^*_y}$ remains unchanged during the execution of the command, then obviously

$$\boldsymbol{\rho\ (X^*_y, x_0) = N\ (x_0) = L\ (\upsilon, \lambda),} \text{ where } \boldsymbol{L = NP}$$

As a special case under constant we have

$$\boldsymbol{\rho\ (X^*_y, x_c) = L_0\ (\upsilon)}$$

The control of each of the levels of the hierarchical structure is realized by generating commands, influencing at the lower level, ultimately providing such a change in the external environment and the state of the robot, which leads to reaching the set goal. In this way, the management task can be described as follows:

The existing functionality

$$\boldsymbol{\rho\ (X^*_y, x_c) = L\ (\upsilon, \lambda)}$$

which in the general case may not be given, but be known by the following realization:

$$\boldsymbol{(x_c, X^*_y) \subset X, x_c = P\ (\upsilon, \lambda)}$$

$$\upsilon \subset \Theta, \lambda \subset \Lambda$$

where X, Θ and Λ are bounded sets of some metric spaces.

It is necessary to build such a control algorithm that provides minimization of the functional and to clarify the conditions that must be satisfied by $L(\upsilon, \lambda)$ to ensure the convergence of the minimization process to $\inf L(\upsilon, \eta)$. It is characteristic that all constraints of the sets X, Θ and Λ can be unknown in advance and it is necessary to specify in the process of solving the problem [1].

If such an algorithm for each level of the controller is built and implemented and is also known for each of the possible commands its representation in vector form or as a subset, and also known the operator of the conversion of information from the sensory information system into the situation vector, the execution of each command from the robot is reduced to the implementation of each of the control levels of the algorithm of minimization of the functionality, which translates the commands from the higher rank level into the commands at the lower rank level, being a translator program.

3. Organization the Low-Level Control of AnRI Service Robots

The low-level of control is a level that has a direct impact on the degrees of mobility of the working systems of the robot by forming control commands. This level performs the task for tactical actions, which is formed at the highest tactical level in the multilevel hierarchically built control system.

At the highest level, strategic decisions are made, which lead to the achievement of the set goals in accordance with the set restrictions. There are also procedures with elements of artificial intelligence for recognizing and identifying the information received from the sensory information system in order to create an adequate model of the environment and its impact on the robot.

The space of the low-level situations could be expressed as

$$X \equiv \Theta \subset Rn$$

respectively of the setting $x_y = \upsilon_y$ and the vectors of the situation $x_c = \upsilon_c$ are n-dimensional vectors of Θ. The operator P in this case is a single matrix. The set Θ is bounded by the n-dimensional parallelepiped

$$0 \leq \upsilon_i \leq \upsilon_{max}, \quad i = 1,2,3,\ldots, n$$

and its elements are solutions of the differential equations describing the drives of the degrees of mobility of the executive body. The minimizing functionality does not depend on the state of the environment and is a norm of the differences of the positioning and situation vectors.

$$L_\upsilon(\upsilon) = \| \upsilon_y - \upsilon_c \|$$

The minimization of the functionality at this level is carried out at the expense of the formation of the management of the drives of the degrees of mobility of the executive bodies. Relevant minimization algorithms are described in detail in the literature [15].

4. Description of the created Robots "AnRI-1" & "AnRI-2"

The Robots "AnRI-1" and "AnRI-2" (Fig. 1 and Fig. 2) are realized on the base of constructions of mobile platforms with four wheels, which two are driven and two are independent "free" wheels. The wheels in the Robot "AnRI-2" are located in the form of "cross". The "free" wheels are at the rear side one and in front side the other of the platform. The driven wheels are at two sides. With the help of this construction of the platform, it is possible to control the Robots movements around the vertical axis around geometrical center of construction in the left and right sides [13].

Fig. 1. View of the Service Robot "AnRI-1"

Fig. 2. View of the Service Robot "AnRI-2"

Electric motors, DC powered by a rechargeable battery are built at the hub of the driven wheels. "Worm" gearboxes that do not allow movement back using their braking effect, are used in the driven wheels of the Robot platform.

The same construction has the Robot "AnRI -1" with different position of the wheels, which are mounted in the form of "triangle". In front of the two tops of the triangle are located the driven wheels and at the third top in the rear side is two "free" wheels.

The manipulator of anthropomorphic type with three regional and three local degrees of mobility and gripper with separate drives and with three fingers, is mounted at the top of the robot "AnRI-1" [11, 12].

4.1. Drive and technical characteristics of the Robot's manipulator

Based on "servo" controllers with feedback from incremental sensors, located in each degree of mobility, the drive of the Robot Manipulator is realized. All regional joints are equipped with electromagnetic brakes.

Technical characteristics of the Robot Manipulator are as follows:

- Coordinate system type is Anthropomorphic type.
- Structure: 3 regionals and 3 local rotational degrees of mobility + driven by the gripper.
- Structure formula is RRR / RRR + Gr
- Positioning accuracy is + - 0.05 mm
- Repeatability positioning accuracy is + 0.05 mm
- Maximum travel speed of the manipulator is 0.3 m/sec
- Maximum travel speed of the robot is 0.5 m/sec
- Power: Rechargeable 12 V. (Rechargeable battery required)
- Weight of the manipulator is 6.75 kg
- Working area dimensions in horizontal plane are 1m x 1m
- Loading capacity is 1.5 kg
- Motor drives are – Electric – DC Servo

It is used Robot Operating System (ROS). Both at regional and local degrees of mobility of Manipulator it is possible to control the speed of execution.

4.2 The control system of the Robots "AnRI".

The Control System of the Robots is hierarchical and distributed type. It is consisting from different levels and is realizes control of different devices and systems. It is possible used corresponding software modules [4, 6].

The connection between all devices on the management is realized via serial interface RS 232. CPU module for total robot control is based on 32-bit microprocessor unit. In the recent years 32-bit microcontrollers are widely used for robot control applications.

Most popular and wide spread architecture is Cortex-M processor family [9]. In our opinion, the Cortex-M4 family is well suited for robot control applications. It is integrating Digital Signal Processing (DSP) unit with processing of floating-point support for fast and a power-efficient algorithm. Therefore, Cortex-M4 can use in digital control applications such as motor control, sensor fusion and power management [9].

In this paper is described a practical realization of Cortex-M4 architectural Control System based on universal I/O board for Service Robots. On the same base is realized control a set of digital and analog inputs, 10/100 Ethernet interface, PWM controls and used CAN, SPI and I2C buses [5]. This configuration enables flexible solution for connecting various sensors and actuators of the robots. In the same time using, the modern Cortex-M4 architecture allows simplify the design and reduce number of external components. This greatly improves the whole system reliability [10].

A block diagram of the developed communication concept for “AnRI” robot control is shown in Fig. 3.

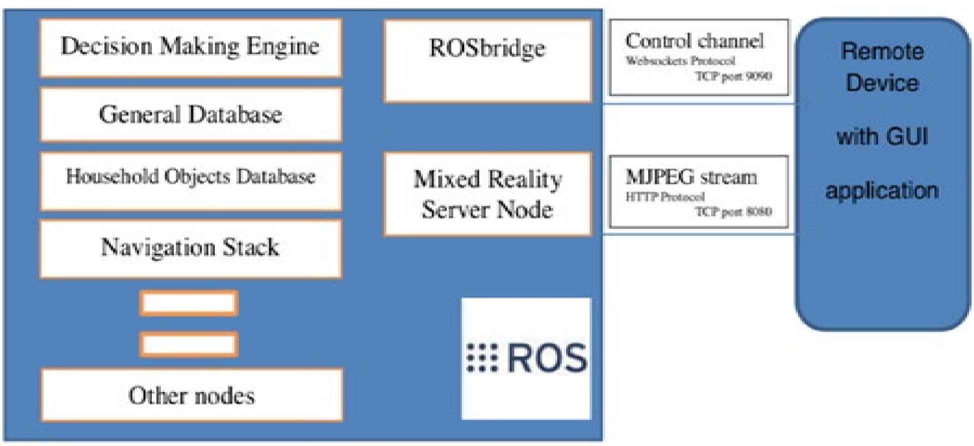

Fig. 3. Block Scheme of the developed communication concept of The Robots “AnRI”

The use of Mixed Reality Server Node plays a special role. This component provides combined information from the mapping server, the navigation component, and the robot's knowledge base for environmental objects. The information is sent as a stream to create augmented reality to the User Interface with Graphical User Interface (GUI). It performs part of the data processing before sending it to the User Interface [4].

This is to optimize the use of the network bandwidth, to realize synchronous access to information from different sources, and to reduce the computational requirements for the device that implements the GUI (Graphical User Interface). Using a standard control TCP/IP [2] network for communication with the board allows platform independent control.

Also, various diagnostic tools and standard libraries can be used for rapid implementation. It is very important, is presented another serial interface module, GPS module for navigation and GPRS for Internet communication [14].

This is allowing to be used of vision module and the module of the laser interferometer, along with integration module, reading and loading data from sensor systems. Used operating system is ROS (Robot Operating System).

5. Conclusion

The article shows the concept of organizing the control of a service robot in terms of its functional characteristics, allowing it to come into contact with the serviced person completely safely. The idea of using the functional characteristics of Collaborative robots, which are mainly used in industry, is considered. The management organization in this case of service robots is designed to serve people with problems. Thus, the service robot is ready to serve human beings, including those with disabilities. The control in the service process is carried out by recognizing voice commands, which is very important from the point of view of user convenience. In addition, the created service robots have the ability to transmit information to trainees not only verbally but also with gestures and actions implemented with the help of service robots from the series "AnRI" (Anthropomorphic Robot with Intelligence). For this purpose, the presence of a manipulator with a three-finger gripper in the robot is used, which allows to generate not only gestures, but also actions and manipulations to help the information contact between the robot – the lecturer and the learner [7, 8].

By using this methodology, an innovative effect is achieved in the special education of children, which is very close in nature to the way information is transmitted between people. The results of the laboratory tests were very encouraging. Young people with normally developed abilities were placed in the role of trainees. The dialogue between the robot and the learner was observed, which ended with a reported number of available cards as a reward for the positive answers received from the learner.

With the use of the robot "AnRI-2", which is equipped with a large screen for additional visualization and illustration of the dialogue, new opportunities are realized in the process of transmitting information to the learner. The innovative approach developed at KyuTech University – Japan, a partner in the CybSPEED project, was also used to transmit information using "keyword". This achieves high efficiency of communication with the learner and the ability to easily and quickly memorize the main points of the dialogue. It should be noted that in this case were used in the implementation of special training and elements of artificial intelligence in the robot – lecturer, as far as voice recognition of the answers received from the trainees, as well as analysis and identification of scenes.

When combining the two robots “AnRI-1” and “AnRI-2” simultaneously in the processes of training and communication with the learner there is an opportunity to use the manipulator of the first robot and the capabilities of the big screen of the second robot to increase the efficiency of dialogue. Thus, a Cyber physical system of two synchronously working robots is realized, realizing the possibilities not only for verbal, but also for gesture communication, complementing the visualization on a big screen and voice recognition.

Within the framework of the CybSPEED project, pilot experiments will be conducted on the territory of the Social Services Centre “St. Nedelya”, Sandanski, Bulgaria with the participation of students from the group of cared for children in the Centre and a team of pedagogues, experts and psychologists. From educators, children are identified as learners and the first experiments in the Centre are ready, after which the first results will be carefully analysed using the service robots “AnRI”, using the expertise of educators from the Centre. to proceed to the application of the created innovative method for teaching children with developmental problems in the pedagogical practice will be taken into account all the remarks and suggestions made by the expert pedagogues in order to improve the algorithms used in robot control. Specific lessons will be generated and refined in the process of work with the help of experts - pedagogues from the Centre.

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