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# CONTROL SYSTEM OF THE ANTHROPOMORPHOUS ROBOT FOR WORK ON THE LOW-ALTITUDE EARTH ORBIT

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**Abstract:**

This article presents a control system of an anthropomorphic robot that can work in low Earth orbit in open space. Design of the manipulator that allows working with the tools of the cosmonauts is examined in the second part of the article. Kinematics and structural scheme of the manipulator are shown on the schemes.

Further the general block diagram of the control system is presented, which considers requirements during the work on ISS. The architecture software scheme and components description is shown in the last part of the article.

**Keywords:** Robotic system, anthropomorphic robot, international space station (ISS), manipulator, control system, extravehicular activity of astronauts.

## 1. Introduction

Current piloted astronautics is developing with restrictions caused by human factors (specialization of crew members, duration and conditions of extravehicular activity, etc.).

A competitive advantage in achieving a leading position in the piloted astronautics can be obtained through use of series of innovative solutions. One of them is the use of robotic systems [1]. Such system could provide functionality similar to the one of an astronaut in both accuracy and complexity. Creation of such systems can be seen in the works done by foreign space agencies. Such developments are conducted also by domestic authors.

In this work we consider development of the functional and structural diagrams of a control system of the robot of anthropomorphous type (RAT) that can work in the conditions of low-altitude earth orbit.

## 2. Rat Manipulator Design

The RAT design has 2 manipulator modules. Each of them has 7 degrees of freedom. The kinematic scheme of the manipulator is presented on figure 1. It consists of 6 main links: 1C - the module for gripping devices; 5M and 4M - include mechanisms to turn, to capture and rotate the forearm; 3M and 2M - compose the mechanism to turn the elbow node and turn the shoulder in the XY plane; 1M - the link to carry out the turn of the shoulder joint in the YZ plane.

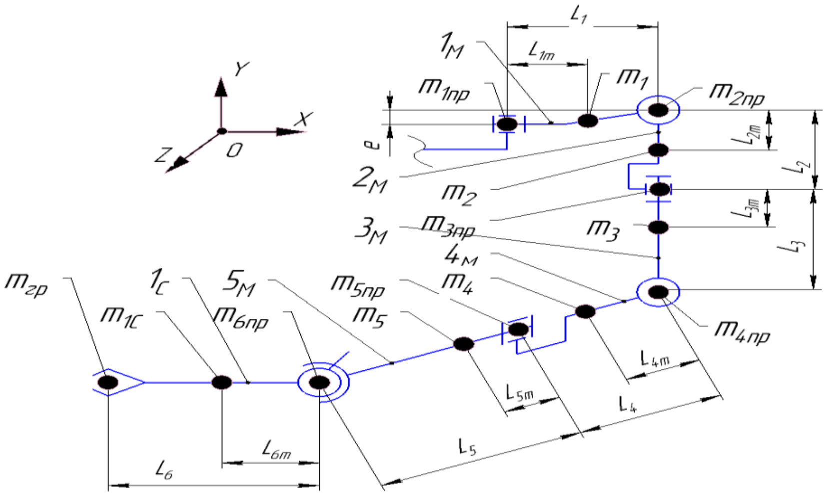


**Figure 1 - Kinematic scheme of the manipulator module.**

where 1M,2M,3M,4M,5M - manipulator links, 1C - the gripping module, e - the eccentricity showing distance from axis of sqew of the first drive to the center of gravity of the second drive, m; Li - lengths of links of the manipulator, m; Lim - distances from the centers of gravity of links to axis of their rotation, m; mgr - the mass of load, kg; mi - the mass of links of the manipulator, kg; mipr - the mass of position of the centers.

In figure 2 the block diagram of the manipulator module is shown. The following designations of turning angles and drives for each link are used: k6 and k6' represent the gripping module turning angles, associated drives are 6pr and 6pr’. Q5 is the angle of rotation of the forearm, it is activated by drive 5pr. Phi4 and 4pr designate the forearm turning angle and the corresponding drive. Rotation of the shoulder by and angle q3 is achieved by drive 3pr. Finally, drives 2pr and 1pr are responsible for turning the shoulder by an angle phi2 in the XY plane and angle phi1 in YZ plane respectively.

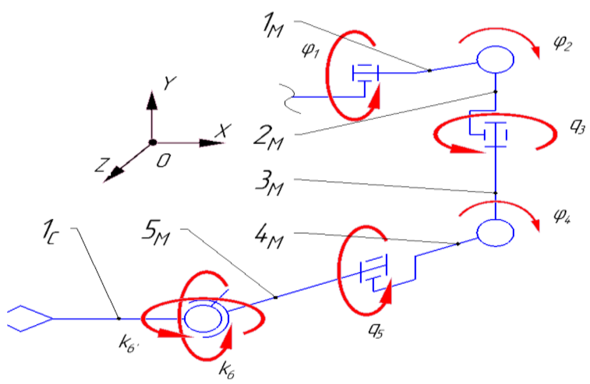


**Figure 2 - The block diagram of the manipulator, where φi - turning angles of links; qi - rotation of links.**

This scheme is createdsimilar to the mobility of a hand of a person. Kinematic couples presented on the schemes correspond to similar parts of a body of a person:

- mobility of the shoulder joint and the shoulder itself are implemented by means of kinematic couples of M1, M2 and M3;
- the elbow joint mobility is implemented by means of the kinematic couple of M4;
- mobility in forearm is achieved with the kinematic couple of M5;
- the mobility of the manipulator similar to mobility of a human wrist is reflected in kinematic couple of 4th class with the crossed suspension axis - M6.

The kinematics of manipulator modules is similar to the one of a human hand and provides larger service zones and operation angles than an astronaut dressed in a space suit The fragment of the general diagram of the preliminary design study of the RAT is given in figure 3.

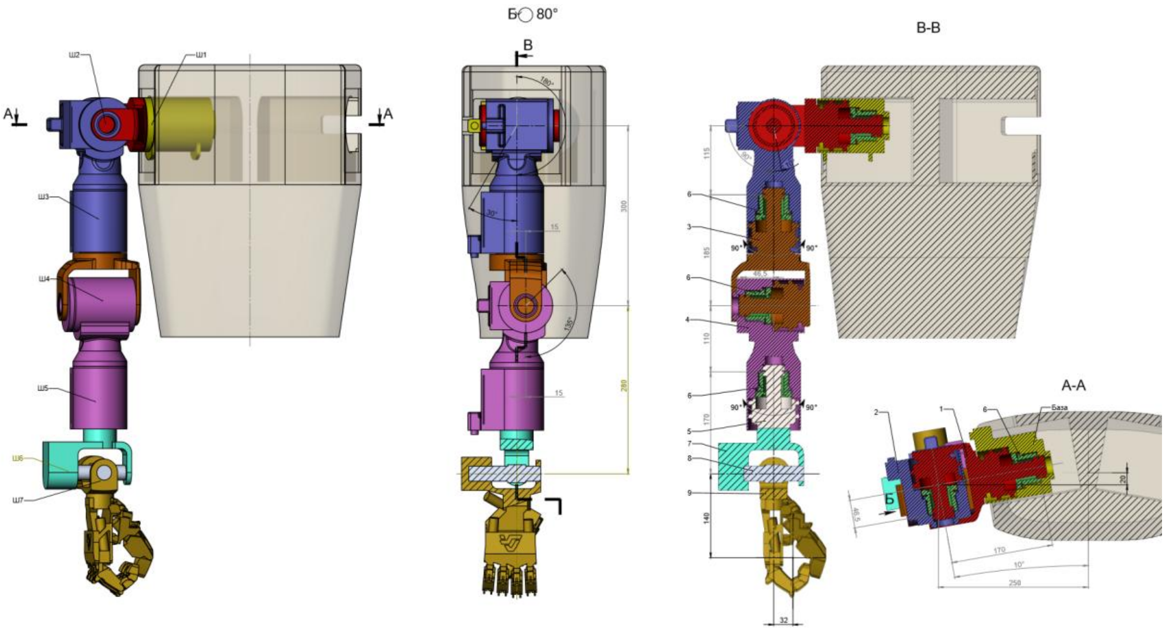


**Figure 3 - Design study of the RAT (the simplified look), where 1-9 - the enlarged assembly units the RAT.**

## 3. Block Diagram of the Control System

The developed block diagram of the control system consists of three main units:

- The block of reception of managing signals - it is implemented in the form of the device of a copying type (DCT). A DCT consists of the controller, the lever mechanism with recording systems of the relative turnangles of the links and power loading of the left and right hands of the operator.

  The recording system provides measurement of the turning angles of hinges of the lever mechanism by means of the absolute magnetic encoders that are installed on the rotation axes of its links. Values of the angles are transmitted by means of the synchronous digital SPI interface.

The system of the power loading creates in hinges of the lever mechanism the torques proportional to forces operating in the corresponding nodes of the manipulator for creation of feedback on effort. The system consists ofthe collector electric motors with reducers, controllers of power management, power modules, sensors of momentsand forces.

Connection of the DCT to the block of transformation of managing signals and data transmission is carried out usingthe Ethernet.

- The block of transformation of managing signals - the main node of control system, is based on the personal computer withMicrosoft Windows operating system. The special software installed on the personal computer allows to make the management of the RAT main systems and to trace their state.
- The block responsible for creating and delivering of control sequences - is implemented directly on RAT. According to requirements [1] for data transmission the MIL-STD-1553 protocol, or its analog of GOST P 52070-2003 has to be used. The separate modules which are responsible for control of engines and data retrieval from sensors and encoders are constructed using the microcontroller Milandr1986BE8T with ARM Cortex-M4F architecture. This microcontroller is radiation resilient, has hardware support of the state standard specification P 52070-2003 protocol, is certified to work in the conditions of the outer space and has the built-in protective systems from failures. Operating temperature range - from -60 °C to +125 °C. The architecture of system is presented on figure 4.

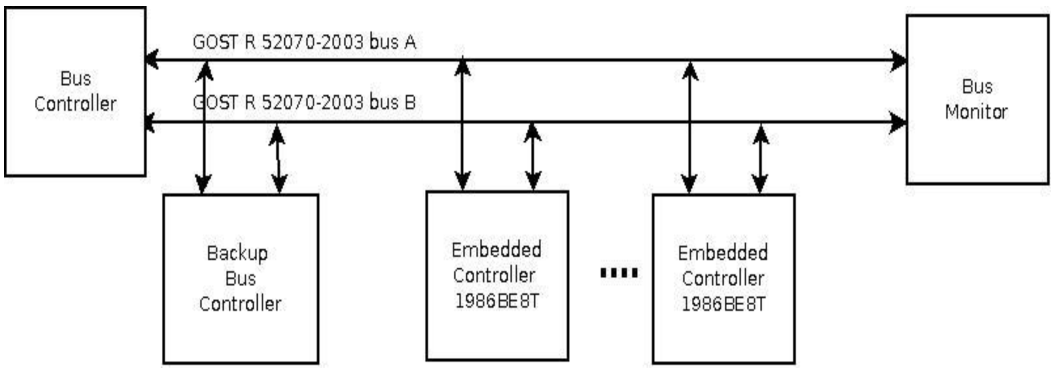


**Figure 4: Architecture of a network of the state standard specification P 52070-2003 standard.**

The bus controller is connected to the block that manages transformation of the control sequences using the Ethernet.

**4. Software Architecture**

The program control subsystems are createdthe developments done for the RAT AR-600. This allowed us to accelerate and simplify creation of the working software prototype [5].

The original software allowed the robot to operate by means of the DCT (fig. 5).


**Figure 5 - The device of a copying type (DCT) "Costume"**

The original software for AR600 consisted of several programs written in VB.NET that communicatedusing TCP/IP protocol. Control sequences were sentto the on-board computer located on a back of RAT. This embedded computer carried out a part of the computing and controlling functions. This scheme is not suitable for work in spacet. In the new project for RAT it was decided to unite all the modules in one program which will work at the equipment available on ISS. The structure of the software is presented in figure 6.

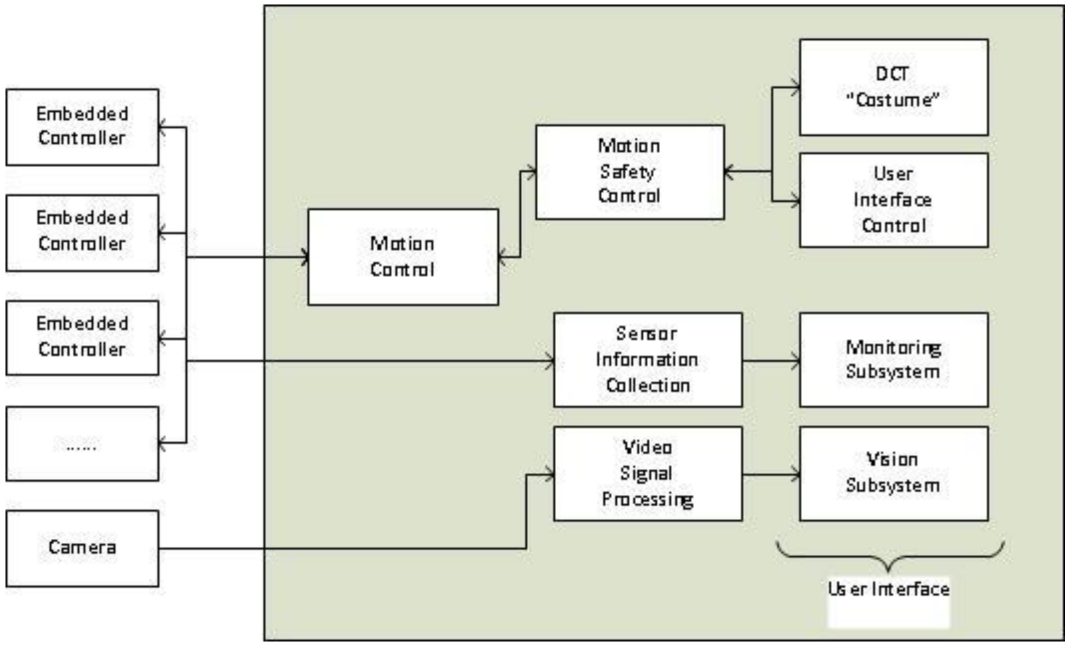


**Figure 6 – Software architecture scheme.**

To create the software control system of the high level .NET stack of technologies and the C# programming language was used.

The control of the RAT can be doneby two ways - by means of the DCT "Costume" and from the user interface of the program.

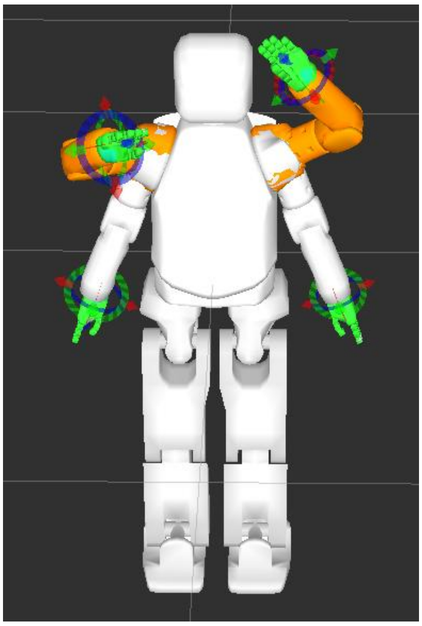

Figure 7 – Model of AR600 inGazebo/MoveIt.

The commands for the movement of the RAT initiated by the user pass verification on safety and only after that arrive directly on the integrated RAT controllers.

The control sequences arriving on the RAT, sensor information and program log are stored in the database and are visualized for convenience of the user.

To save all the relevant information Mongo DB database management system is used. This document-oriented database program uses dynamic schemas that allowed us to develop a clear and convenient system without difficulties of relational DBMS. The possibility of data exchange with the server on the Earth's surface is provided. That saved information will allow us to start in the future development of an intellectual control system of the robot, as well as to monitor the conditions in which the RAT will operate.

Testing of the developed software is carried out in the environment of the Robot Operating System (ROS) with the Gazebo and Move It packages, by means of the adapted AR-600 model shown in figure 7.

**5. Summary**

The RAT manipulator design similar to a hand of the person is the most optimum and has more degrees of mobility, than the astronaut in a space suit.DCT allows controlling the manipulator in the most ergonomic and simple way to learn. Feedback of the DCT accelerates the adaptation of the operator and increases the accuracy of the manipulations.

The control system architecture of the RAT according to the state standard GOST R 52070-2003 with the use of the radiation resistant components provides reliable, steady data transmission in the conditions of low-orbit open space.

The software of the user level makes data processing from all the parts of the control system and allows to operate effectively with the RAT manipulator and to monitor the conditions of the RAT subsystems.

**6. Conclusions**

Use of the anthropomorphous robotic systems to perform various operations in an outer space on low orbit will allow us to increase the performance and to reduce the number of extravehicular activities on ISS.

The developed control system and the DC Tallow us to carry out necessary operations efficiently.

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