



SELECTION OF CONCEPT AND DETERMINATION OF THE MAIN PARAMETERS FOR MANIPULATOR OF DUAL-ARM MANIPULATOR SYSTEM OF PLANETARY ROVER

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ABSTRACT

The article analyzes foreign dual-arm manipulator systems created for space application. The analysis of human anthropometric characteristics is performed and new manipulator system concept is developed based on this analysis. A kinematic structure is developed and technical specifications for manipulator system drives are calculated.

Keywords: dual-arm manipulator system, gripper, degree of freedom, mobility, kinematic structure, manipulator system drive.

INTRODUCTION

Currently, with ever increasing frequency plans for the development of space and nearby planets it is proposed to use robots, which include manipulator systems.

The developed manipulator system is designed to help the astronaut (in load lifting, tool delivery), to carry out joint work with the astronaut or replace the astronaut during the heavy, dangerous or monotonous operations when executing construction, mounting, assembly and transport tasks on the lunar surface. To carry out joint operations the manipulator system dimensions should match the physical dimensions of the human body in order to use the tools and machinery designed to be operated by the astronaut. Manipulator system must exceed the human abilities in terms of load-carrying capacity for the purpose of increasing the effectiveness of the above operations. To carry out operations with oversized objects or hold items of a complex shape the manipulator system must have two arms. Layout of manipulator system drives should provide a maximum working area. Also, to perform complex operations, manipulator system must be able to interact by the arms with each other and ensure uniform movement of objects. In addition, since manipulator system operates as part of the planetary rover mobility system, its own mass should be minimal.

Based on the above, we can formulate the following basic requirements that must be met by the manipulator system:

- overall dimensions should match the physical dimensions of the human body;
- manipulator system should have two arms;
- manipulator system should provide smooth and uniform motion of the end-effector;
- manipulator system arm should have high mobility, comparable with mobility of the human arm;
- drive layout of manipulator system arm should provide maximum working area;
- manipulator system should provide simultaneous operation by both arms;
- load-carrying capacity of one arm should be at least 20 kg at full extent in the Earth's gravity;

- maximum load-carrying capacity of one arm should be not less than 50 kg.
- full mass of manipulator system should be not more than 100 kg;
- maximum gripper translation velocity should be not less than 100 mm/s;
- gripper positioning accuracy should be not worse than ± 3 mm.

The main advantage of the dual-arm manipulator system used for on-planet operations is spaceflight cheapening and increase in the effectiveness of the operations performed, as the manipulator system operating as part of an unmanned planetary rover does not require a special capsule for transportation, life support and nutritional system.

RESEARCH METHODOLOGY

There is quite a number of works devoted to the subject of dual-arm manipulator system. In "Introduction to the mechanics of space robots" [1] G.A. Genta examines the tasks of manipulator system during operation in space, and considers interaction of manipulator system and human. The author discusses the problems associated with the manipulator system operability, which should also be considered when designing. In addition, the relationship between the working area of the manipulator and the drives used is described and characteristics of end-effector (gripper) are provided. Possible gripper types, their description and comparison are given in [2]. Interaction of arms of two-arm manipulator system and execution of joint operations by them is considered in [3].

Design projects of dual-arm manipulator system made by the space agencies of the United States and Germany are known. An overview and analysis of their characteristics in terms of the possibility of executing the tasks assigned to the rover manipulator system is given below.

Robonaut 2 is the second generation of manipulator system developed by National Aeronautics and Space Administration (NASA). The Robonaut 2 arm (Figure-1) is designed by analogy with the human arm and has



similar mobility. The manipulator system arm has 3 degrees of freedom in the shoulder, 1 degree of freedom in the forearm and 3 degrees of freedom in the wrist (gripper). Arm length makes 820 mm, maximum diameter being 127 mm. The distance from the shoulder to the elbow is similar to the distance from the elbow to the wrist and equals to 410 mm. The outstretched arm can lift objects with mass up to 9 kg [4].

The gripper of Robonaut 2 manipulator system (Figure-2) is one of the representatives of five-finger grippers.



Figure-1. Robonaut 2 arm.

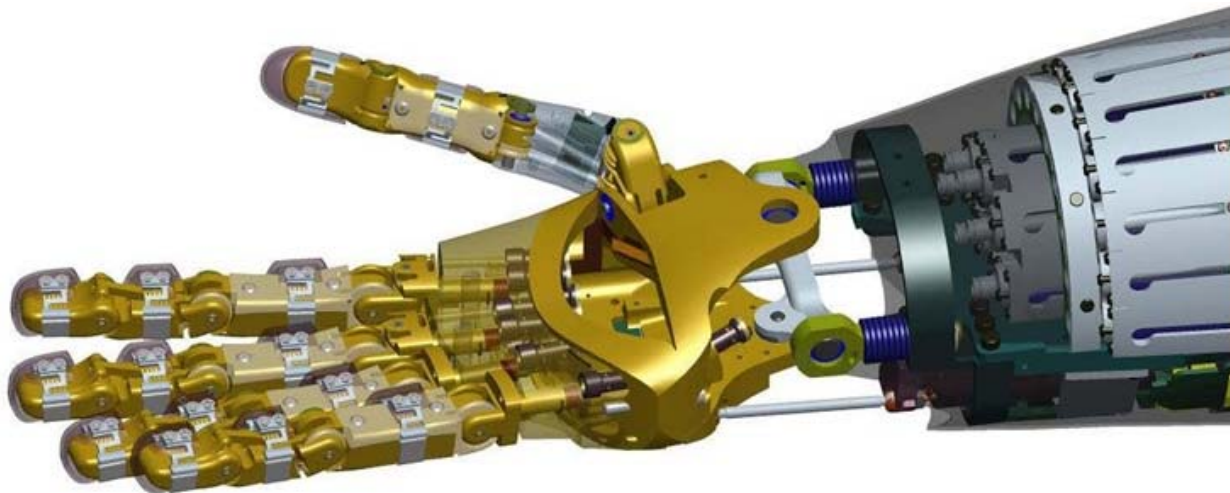


Figure-2. Robonaut manipulator system gripper.

The robot is designed to work together with a man using standard tools, so special attention was paid to Robonaut 2 wrist: it has anthropomorphic dimensions and can take items of different shapes [5].

Forefinger and middle finger have four degrees of freedom, including three degrees of freedom with motor control. The thumb has 5 degrees of freedom, 4 of which are controlled by the motor. Gripper is equipped with tactile sensors, joint position and stress sensors.

Justin was developed by the Institute of Robotics and Mechatronics of National Aeronautics and Space Research Center of the Federal Republic of Germany (DLR). Justin's manipulator arm (Figure-3) has 7 degrees of freedom and mass of 14.8 kg; it can lift objects with mass up to 15 kg. The arm has a modular structure and can be made with a large number of degrees of freedom. Total length of the arm equals to 1,226 mm, translation velocity – 120 ...180 deg/s. An encoder, joint position sensor and

torque transducer are installed in each joint. Axes around which the arm can rotate are shown in Figure-4 [6].



Figure-3. Justin manipulator arm.

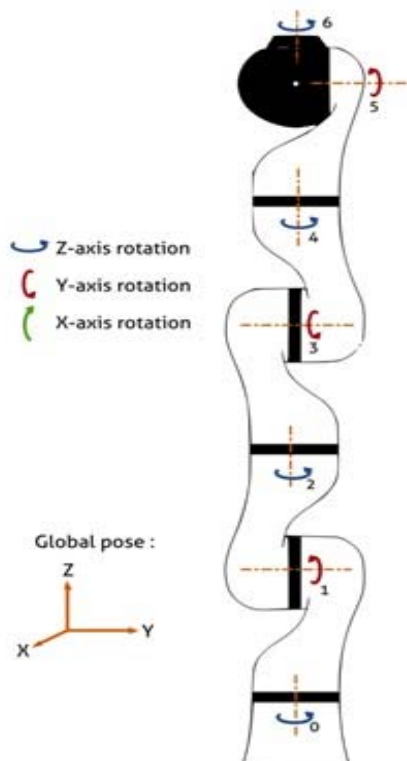


Figure-4. Rotation axes of Justin manipulator arm.

Gripper of Justin manipulator system arm is made as four-finger one with total number of degrees of freedom being 17, including 13 degrees of freedom controlled by electric motors (Figure-5).



Figure-5. Gripper of Justin manipulator arm.

In the gripper, by analogy with the human arm, thumb is opposable to three other fingers [7]. The gripper design allows confidently using electrical tools, since the thumb and two opposite fingers can grasp the tool by a handle and the fourth finger can make the tool operational. The gripper is of modular design; electric motors are located in each phalanx separately. The gripper has phalanx position sensor and six-component force transducer.

Survey of foreign dual-arm manipulator systems developed in NASA and DLR showed that these dual-arm manipulator systems are executed at a high technical level, have high mobility, precision and translation velocity. Both dual-arm manipulator systems are developed using rotational drive, because as compared to linear drives they take less room and enable to increase working area. Justin manipulator system is developed to a greater extent for optimization of the control system with two manipulators and their interaction with each other and surrounding objects inside a space station. Robonaut 2 is designed for operation both inside and outside the space station, in particular to replace the astronaut during monotonous work and execution of visual inspection and repair tasks [8]. To carry out such tasks the dual-arm manipulator system should be able to use any tool intended for the man, therefore Robonaut 2 gripper has 5 fingers. To solve the tasks set out for the planetary rover manipulator system, application of such gripper seems inexpedient since the gripper has a complex design to ensure mobility of all five fingers, which results in increased mass of the robot and decreased reliability in operation. Also, Robonaut 2 arm has high translation velocity, increasing the required drive power, which leads to increase in its mass. However to perform operations with loads on the Moon surface the high velocity is not required, it would be preferable to increase load-carrying capacity of drives within the available power of electric motors. Gripper of Justin's dual-arm manipulator system is of modular design, i.e. each finger phalanx has its own electric motor. Such design results in decreased load-carrying capacity of



the manipulator system arm, as with gripper being proportional to the human arm the electric motors of finger phalanges turn to be insufficiently powerful for handling heavy objects. Also, according to the announced information, Justin's arm can lift objects up to 15 kg, which does not meet the requirements specified for the developed dual-arm manipulator system.

The performed analysis of dual-arm manipulator system allows drawing a conclusion that currently there are no dual-arm manipulator systems designed for executing heavy-duty operations, such as construction,

installation, assembly or transportation on the surface of the Moon.

The dual-arm manipulator system is developed on the basis of analysis of human anthropomorphic characteristics and foreign dual-arm manipulator systems. Since the developed dual-arm manipulator system is intended for carrying out joint work with the astronaut, the dimensions of its component parts should match anthropometric characteristics of an average man, Figure-6.

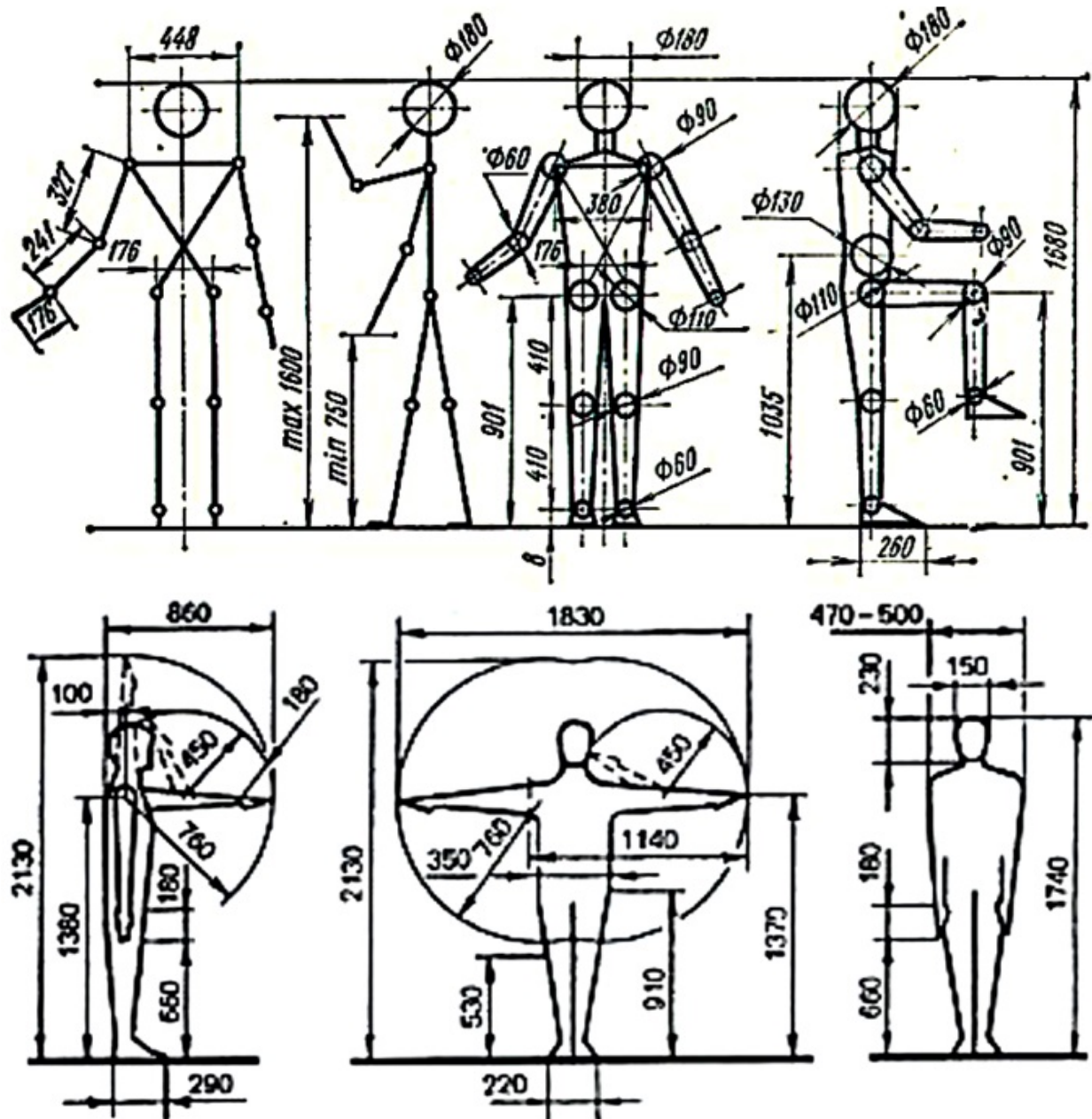


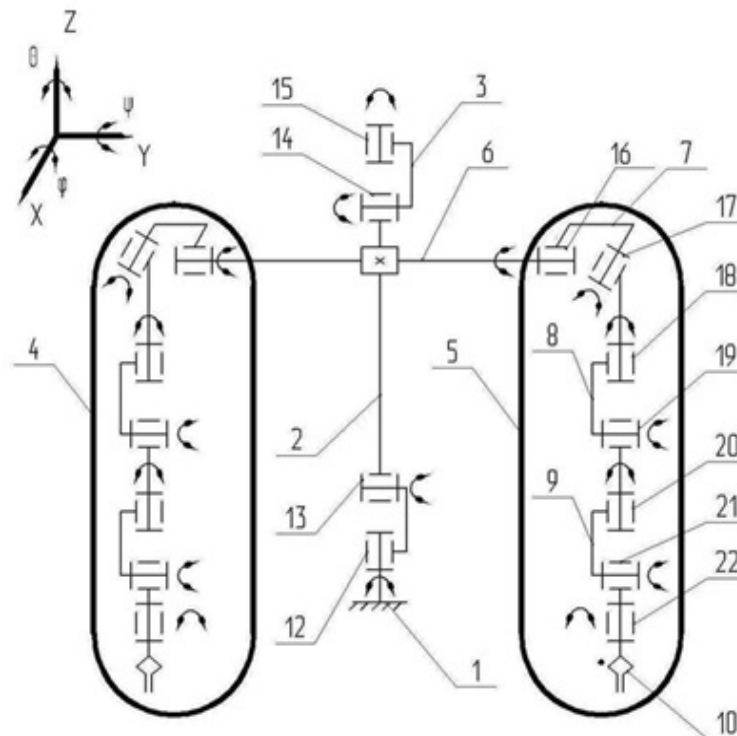
Figure-6. Anthropometric characteristics of an average human being [9, 10].



To transfer an object to any point of space the manipulator must have three degrees of freedom. For the orientation of the object at a given point the manipulator must have three more degrees of freedom. Thus, six degrees of freedom are sufficient for an object transfer and orientation at any point in space, limited only by the arm length. To perform tightening or loosening operations with threaded items, loosening or tightening of fasteners with special tools an additional drive in front of end-effector (gripper) is required. Therefore, it is assumed that developed manipulator system should have seven degrees of freedom in each arm. In addition, seven degrees of freedom give

opportunity to choose the best option from the point of view of ensuring smooth movement [11].

By analogy with the human arm and to increase the working area of the dual-arm manipulator system the drives are arranged as follows: three rotation drives being installed in the shoulder, one in the elbow and three in the wrist (Figure-7). Such arrangement ensures also high mobility of the arm and facilitates the control of the dual-arm manipulator system when two arms interact with each other.



1 – robotic system PC body; 2 – torso; 3 – head; 4 – right arm; 5 – left arm; 6 – shoulder girdle; 7 – shoulder; 8 – forearm; 9 – wrist; 10 – gripper; 12 – torso rotation drive; 13 – torso swivel drive; 14 – head swivel drive; 15 – head rotation drive; 16 – shoulder swivel drive; 17 – shoulder bend drive; 18 – shoulder rotation drive; 19 – forearm swivel drive; 20 – wrist rotation drive; 21 – wrist swivel drive; 22 – gripper rotation drive.

Figure-7. Kinematic scheme of the manipulator system.

Three rotation drives refer to the group of translational ones; these are shoulder swivel drive, forearm shoulder swivel drive and wrist swivel drive. Two rotation drives refer to the group of orienting ones; these include shoulder bend drive, shoulder rotation drive, wrist rotation drive. Gripper rotation drive is used to increase the possibilities of the manipulator system.

It is assumed to make the manipulator system arm with a three-finger gripper, as five-finger and four-finger schemes are excessive and when operating within maximum load-carrying capacity they are unreliable due to complicated design of the fingers. Three-finger gripper design includes two fingers located at the edges and

opposed to one located in the middle. Small-sized items will be grasped by fingertips, therefore two fingers opposed to the middle one should have additional drives to measure the distance between them. In total the fingers have 5 degrees of freedom. The gripper should be equipped with finger position sensor, as well as force and torque transducers for its sensory capabilities. The gripper design being simple and reliable provides safe grasping of an item of any shape.

Adaptive gripper developed by Robotiq is a typical example of a three-finger gripper (Figure-8) [12].



Figure-8. Three-finger gripper for Robotiq manipulator system.

For complete analysis of mobility kinematics of the manipulator system arm let us analyze maneuvering performance. Maneuverability characterizes manipulator system mobility with rigidly fixed gripper. To avoid obstacle collision and carry out complex operations with objects, manipulator system maneuverability should be greater than zero [13].

Let us calculate maneuverability of the developed manipulator system by the following formula:

$$m = W - 6 = 7 - 6 = 1$$

where m — manipulator system maneuverability;

W — number of degrees of freedom.

RESULTS

Proceeding from the specified requirements of the analysis of foreign manipulator systems and human anthropometric characteristics, the following values for the manipulator system arm were selected. The total arm length from the shoulder to the middle of the wrist makes 845 mm. The arm consists of a shoulder segment 345 mm long, the forearm 345 mm long and wrist 155 mm long, see Figure-9. The distance between the shoulders is 500 mm.

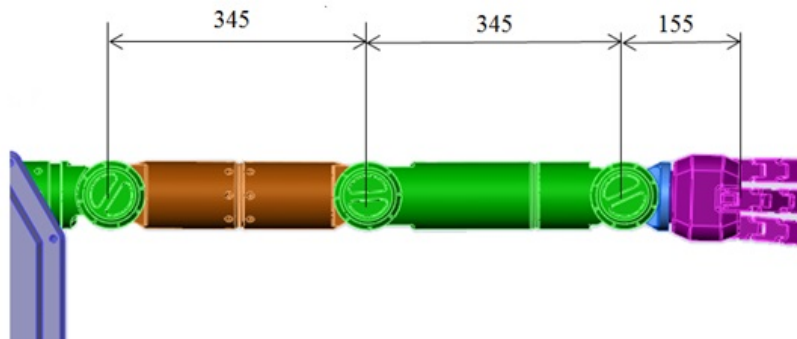


Figure-9. Overall dimensions of the manipulator system arm.

Load-carrying capacity of the manipulator system should provide manipulation with the objects with mass 20 kg at the completely outstretched arm. The calculated characteristics of shoulder, forearm and wrist drives are given in Table-1.

Table-1. Technical specifications of drives.

Drive name	Torque, Nm	Rotations per minute, rpm	Required power, Wt
Shoulder swivel drive	253,5	0,5	23
Forearm swivel drive	130	1,0	23
Wrist swivel drive	34,1	1,0	6

Values of shoulder bend and rotation drives comply with the values of shoulder swivel drive. Values of wrist rotation drive and gripper rotation drive match with the calculated values of the wrist swivel drive.

General view of the developed dual-arm manipulator system is shown in Figure-10.

Rotations axes of the drives relating to the group of orienting ones are indicated by blue color on the right arm. Rotations axes of the drives relating to the group of translational ones are shown by pink color on the left arm, and green color shows rotation of the gripper rotation drive.

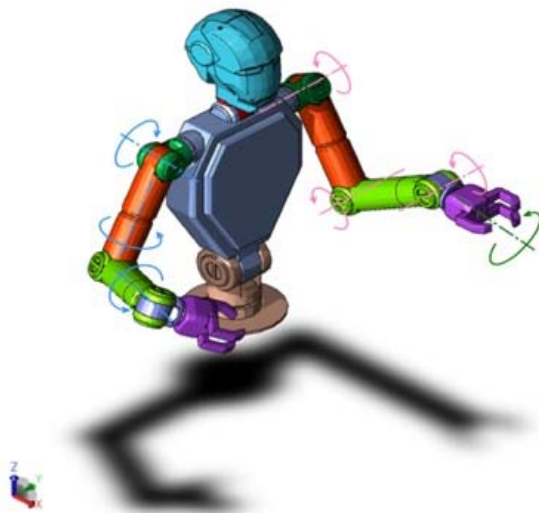


Figure-10. Dual-arm manipulator system.

CONCLUSIONS

The developed dual-arm manipulator system is designed to perform any tasks on the surface of the Moon, starting from independent operations to the joint work together with the astronaut. Owing to the design of arms and grippers the manipulator system can interact with the objects of small mass or shape, as well as with oversized and heavy objects. The developed manipulator system differs from the discussed dual-arm manipulator systems in a greater load-carrying capacity, but it has a low velocity compared to them. The arm of the manipulator system is made with seven degrees of freedom, which ensures its high mobility and maximum working area. Three-finger gripper enables to greatly simplify the gripper design and make it more reliable despite a slight deterioration of grasping ability, compared with the counterparts.

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