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SCIENTIFIC LIFE

ROBONAUT 2: MISSION, TECHNOLOGIES, PERSPECTIVES

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Abstract. The paper focuses on key aspects of scientific and technological solutions implemented in the joint project of NASA and General Motors, Robonaut 2, a humanoid robot designed to work in space as a real assistant to astronauts.
Key words: Space robotics, Robonaut 2, ISS.

1. Mission

Robonaut 2 is the first humanoid robot designed to work in space. It was a joint project of NASA and General Motors. The development of the project has taken about 15 years [1].

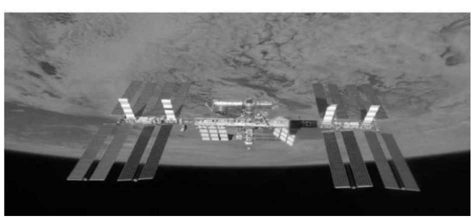
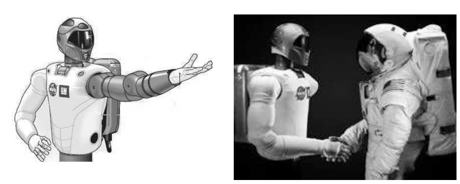


Fig. 1. International Space Station (ISS)



(a) (b)

Fig. 2. (a) Robonaut 2; (b) Astronaut assistant

Robonaut 2 was launched to the International Space Station on February 24, 2011 within the Mission 133 (Fig. 1).

The overall project concept is the robot to be able to function as equivalent astronaut, both inside the station and in the outer space, alone or together with an astronaut (Fig. 2(a), (b)).

At the current stage of the development, Robonaut 2 is characterized by the following functional capabilities: it recognizes objects visually and performs variety of manipulations, it catches solid and rigid objects, it works with both hands simultaneously or separately with a wide range of speeds, it can press buttons on a control panel, it holds firmly for long a measuring device, it can write the words “hello world”, it does shaking hands with a human, it makes gestures. The Robonaut 2 is designed in such a way that it is not possible to injure a human being when works together with him or her.

2. Technology solutions

The robot is developed on the basis of new technological solutions, which include: serial elasticity of joint links, overlapping workspace of both hands, joint controllers with minimal and ultra high speed control, force sensitivity of the palms and the fingers. The robot reaches the flexibility of the human hand and in the same time it carries significant loads. It can carry a load of 20 kg in horizontally extended position of the arm.

2.1. Specifications

Robonaut 2 is “skilful, subtle and strong” two-handed humanoid robot. It consists of head, torso (no legs), two upper limbs and two hands with five fingers. It is made of aluminium, metal and non-metal materials and weighs about 140 kg. It is equipped with a computer system that processes information of 350 sensors, four cameras with high resolution and an infrared camera.

Robonaut 2 has 49 degrees of mobility. They are: (7×2), 14 for the two upper limbs, (15×2), 30 for the two hands with five fingers each, three degrees of mobility of the torso, and two degrees of mobility of the head [2].

2.2. Control System Architecture

The block architecture of the control system is shown in Fig. 3.

The blocks perform the following main functions: a block for global monitoring of the operations, a block of remote connection to the robot, blocks for immediate visual and audio communication with the robot, blocks of direct robot control for an assigned task, an interface block to form state vector containing complete information for simulation and visualization of the overall robot performance [3].

The control system supports two basic modes: autonomous and remote.

2.2.1. Autonomous mode

The autonomous control is the main control mode for the Robonaut 2. The autonomous is supervised, i.e. the process is controlled by a higher level,

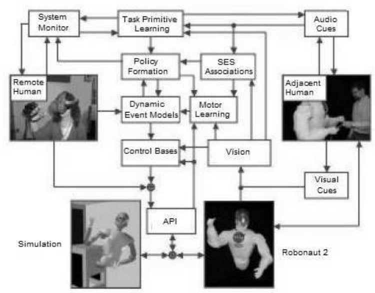


Fig. 3. Control system architecture

which plays the role of task assignment. The robot recognizes objects and performs automatically pre-programmed operations for this object. The autonomous control is used in well-defined tasks and Positional-Integral-Derivative (PID) control algorithm is implemented for the positioning operations. Additional PID algorithms control the movements at a desired rate, desired stiffness and desired compliance. The overall dynamic behaviour of the robot arm is close to the human hand.

The autonomous control mode provides necessary control of the stiffness and the compliance of the hands, palms and fingers. The generated controls are limited, allowing safe proximity between the robot and the astronaut. The robot movement can be stopped quickly and easily when an unexpected situation emerges. Thus realized, the control technology allows joint and safe work between the robot and the astronaut.

2.2.2. Remote mode

In remote control mode, the human operator is placed in the actual loop of the control system of the robot. The method of control is "master-slave", which means that the robot repeats/follows the movements of the operator. The technical means to implementation of the remote control are the Helmet Mounted Displays (HMD), a power glove and tactile feedback devices monitoring postures and movements of the operator. Using these technologies, the operator has a sense of presence at the robot position and a sense of contact within the robot environment. Visual feedback is implemented by cameras with high resolution, mounted in the robot's head. The technology of remote control allows intelligent capabilities of the operator to be used for working on complex manipulation tasks in cases of incompletely formalized conditions, emergency situations or errors.

The relationship between the operator and the robot is performed by an interface called Application Programmer's Interface (API). The unit API provides 100 dimensional vector of sensory-motor signals grouped into data of forces and moments of the upper limbs, the hands, the fingers and tactile information on the palms of the hands.

3. On board tests

The main job of the robot will be to monitor the status of the ventilation system inside the station. This task is very important and vital for the astronauts because it ensures that pipes are not blocked for some reason. The task requires to hold a specific gauge inside the station and to measure the airflow speed in the ventilation pipes.

The difficulty for astronauts in this task is that the measuring device must be kept fixed continuously and firmly for long. This is difficult for the astronauts, because they are easily movable in microgravity and in addition, readings can be easily changed by astronaut breathing near the measuring points.

Also, it is necessary periodically to replace the air filters of the ventilation system which operations are planned to be performed autonomously by the robot.

The arrival to the International Space Station, unpacking and meeting the Robonaut 2 on board is shown in Fig. 4.

Fig. 4. Unpacking and meeting on board

At the ISS the Robonaut 2 goes through a full program of detailed tests, adjustments and elaborate checkouts.

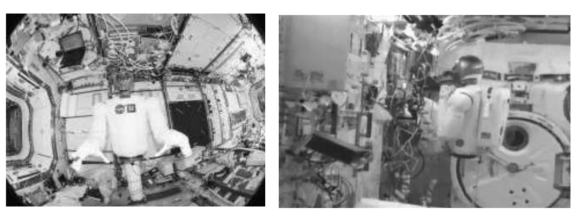


Fig. 5. On board installation

The robot is rigidly mounted on a pedestal, located in the so-called Destiny Laboratory of the station, shown in Fig. 5.

In such a position the following tests are performed [4]:

Test A. Full range of movements of each hand separately and both together, of wrists and fingers, Fig. 6.

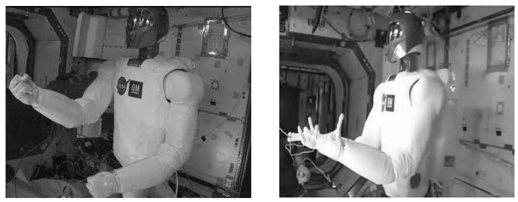


Fig. 6. Test movements of hands, wrists and fingers

Test B. Handshaking with the crew commander [5] and demonstration of flexibility by sign language gestures, Fig. 7.

Fig. 7. Handshaking and sign gestures

Test C. Demonstration of key shifting and button pressing [6] on a control panel, Fig. 8.

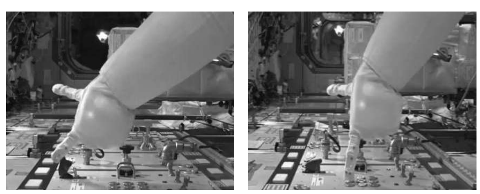


Fig. 8. Key shifting and button pressing on a control panel

Test D. Continuous and stable fixing of a gauge in a specific position point taking a measurement, Fig. 9.

The test task demonstration has been performed in real-time. The robot has performed two measurements which have been transmitted remotely to the terrestrial group for monitoring the experiment. The task of measuring the airflow speed of the ventilation system is reported successfully realized [7].

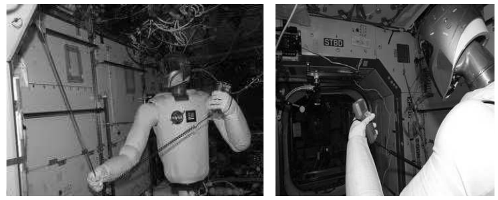


Fig. 9. Taking measurements of the air flow

4. Perspectives

Future activities in space will require use and implementation of a variety of systems and tools. It is obvious that humans and robots have their own specific areas of action but it is also clear that their appropriate combination leads to more efficient usage of resources, enhancing safety and reducing research costs.

Future robotic operations inside the station will be focused on real time tests of operational conditions, replacement and assembly of components.

The next technological solutions of Robonaut are characterized by increased autonomy and considerable flexibility of operations. Experiments with four versions of Robonaut models with improved control algorithms are under experimentation. A prototype of the lower limbs (legs) of the next Robonaut is already developed [8].

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