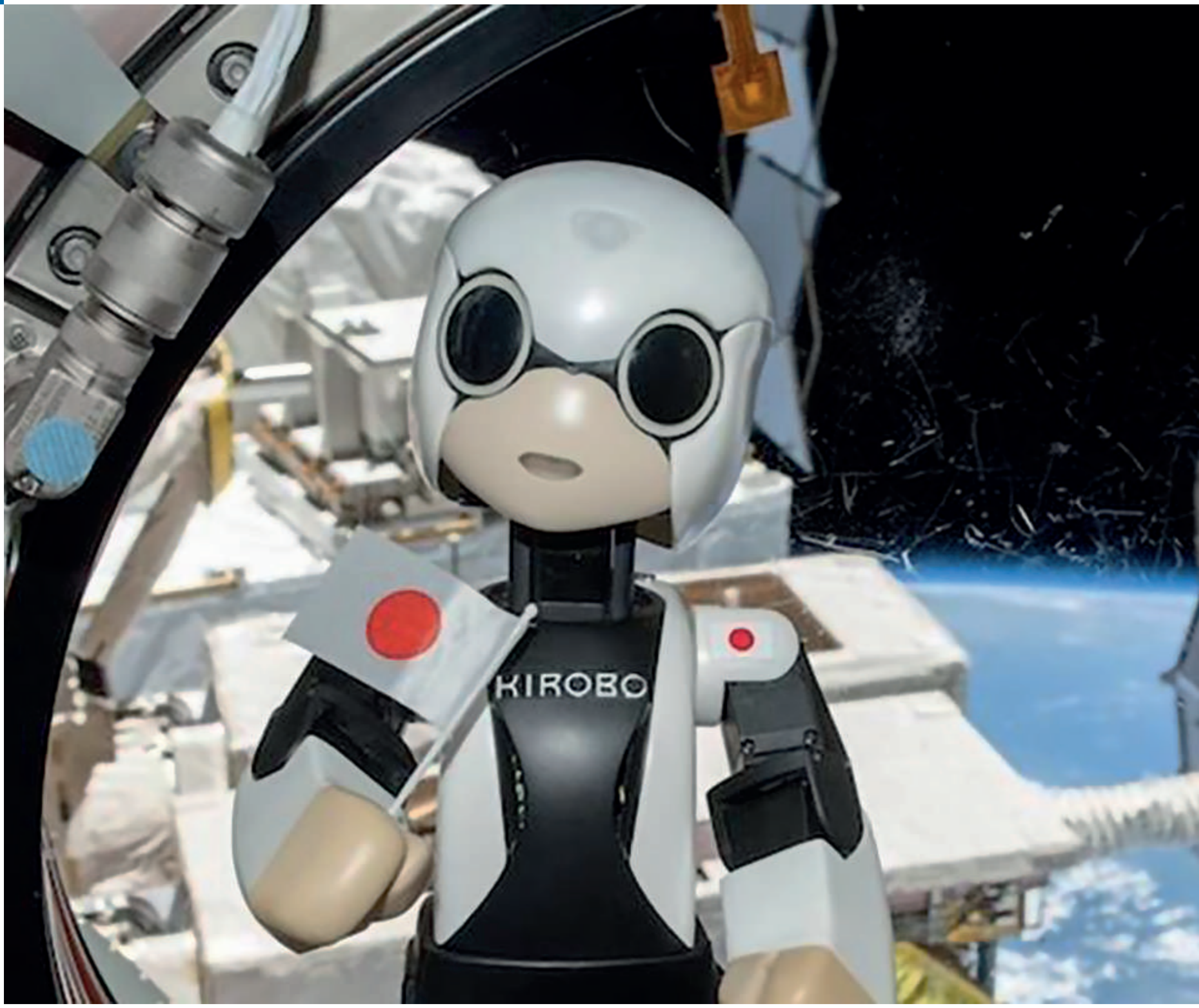

▶ Japan's Kirobo was designed to help researchers explore the possibilities of coexistence with robots during long space voyages of the future.

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Robotic systems for psychological support

The subject of psychological support for spacefarers, either on long-term orbital missions or lunar and planetary missions, is of increasing concern. Here, the authors review some of the technical issues surrounding the provision of robotic support and preview work on the design of human-interaction systems that will, one day, become a standard feature in long-term space missions.

In the classical sense, psychological support for astronauts or cosmonauts is provided by a combination of means, methods and measures to ensure the normalisation of a crew's attitude in the difficult conditions of spaceflight. Support systems aim to socialise crewmembers by maintaining good health, mood and high performance and are based on providing the crew with information covering various aspects: emotional, individual-personal and socio-psychological.

Research has shown that the addition of a psychological support robot to a crew would have a number of positive effects during long-

▲ Sirius19 crew comprising Evgeniy Tarelkin, Daria Zhidova, Stefania Fedyay, Reinhold Povilaitis, Allen Mirkadirov and Anastasia Stepanova.

term and interplanetary space flight, including reducing stress levels, creating a positive attitude, reducing feelings of loneliness and increasing communication activity in the crew. Indeed, numerous studies of human and social robot interaction have shown that effective communication between them is based on a deep understanding of the communicative process and the correct choice of behaviour model. Meanwhile, empirical evidence from social robots designed to operate within an assistive environment suggests some positive effects of social robotic therapy.

In recent years, we have seen the growth of interactive technologies and new ways of using them to treat different mental problems. Among the methods we can distinguish are online, computer and even virtual approaches to cognitive-behavioural therapy, while the use of robots to provide emotional support for workers in extreme conditions in isolation from ordinary life is also important.

Researchers have already coined a new term, ‘robot therapy’, to describe the different ways these ‘social robots’ can be used to help people and there are specialised robots to assist children, adults or the elderly with cognitive, social or physical problems. Research has already shown that social robots can help to improve the quality of life for many people.

Robot assistance in space

The International Space Station (ISS) is currently using standard types of psychological support for

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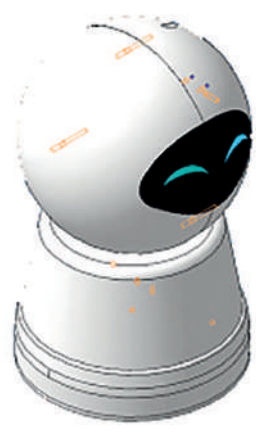
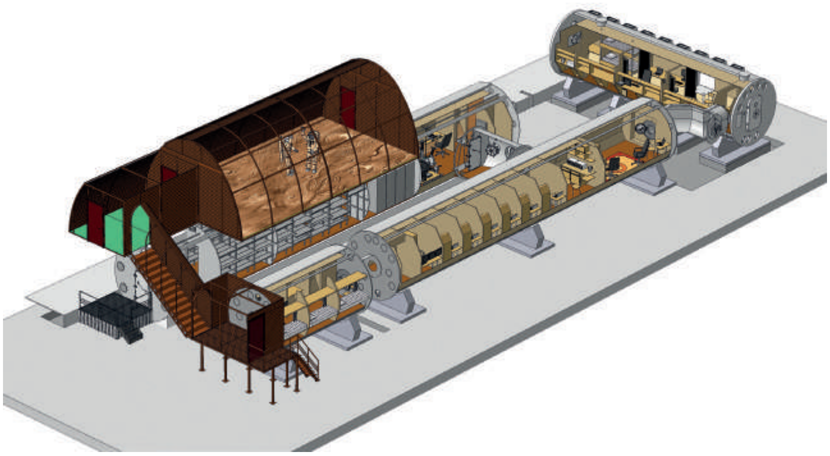


▲ 3D model of robot R-pod.



▲ The Sirius19 research was conducted in the ground based research facility NEK.

astronauts: audio and video communication with relatives via satellite Internet; the ability to watch movies and TV series, and listen to music; the use of virtual reality glasses; and consultation with a psychologist and receiving packages from Earth.

The following is a summary of the development of robots with psychological support or assistance capabilities aboard the ISS:

1. CIMON (Crew Interactive Mobile CompanioN) is a 5 kg ball-shaped mobile and autonomous assistance system designed to support astronauts in their daily tasks. It flies freely around the ISS and uses the principles of artificial intelligence for communication. It can answer questions, take photos and videos, display and explain information for experiments or repairs, and even search for objects.
2. Int-Ball (JEM Internal Ball Camera) is an experimental, autonomous, self-propelled and manoeuvrable spherical chamber developed by the Japan Aerospace Exploration Agency (JAXA) and operated by the agency's ground control team. The Int-Ball floats naturally in the Space Station's microgravity, which allows it to manoeuvre freely. The device has a lot in common with drone traffic ground-based control systems and unmanned aerial vehicle cameras. The simulated 'eyes', which are modelled on the outer surface of the ball, represent the direction of its 'gaze', which is actually a single camera lens located at the approximate centre of the 'eyes'.
3. Kirobo is the first Japanese robot-astronaut developed by the University of Tokyo. The robot's capabilities include voice and speech recognition, natural language processing, speech synthesis, telecommunications, face recognition and video recording. Kirobo is specially designed to navigate in microgravity and assist the Japanese astronauts in various experiments. Its main goal is to see how well robots and humans can interact, hoping that this will lead to robots taking a more active role on missions.
4. Until recently, the structure of psychological support in long-term space flights was based on compensating for the astronaut's sensory deprivation and monotony, mainly using visual stimuli (films, books, news video programmes, photos, paintings, etc.). However, the experience of psychological support for long spaceflights indicates that some crewmembers clearly prefer auditory stimulation, such as music or audiobooks. The need for this may be increased due to the heavy load on visual analysis during the flight (operator activity, observation, etc), and a monotonous set of auditory stimuli, mainly caused by a high noise level on the ISS, which requires the use of active noise suppression systems. Thus it seems likely that the expansion of the spectrum of external stimuli due to auditory information constitutes a significant source of psychological support.

R-Pod is designed as a complete product for audio-visual interaction with a crewmember through a multimedia system and a drive unit that implements the basic elements of emotional dialogue

Introducing R-Pod

The development of the R-Pod robot began as part of a graduate work programme at Bauman Moscow

State Technical University and was conducted within a study of psychological support in the SIRIUS project. One of the authors participated in a four-month simulated space mission, SIRIUS-19, in which the need for additional means of psychological support became obvious.

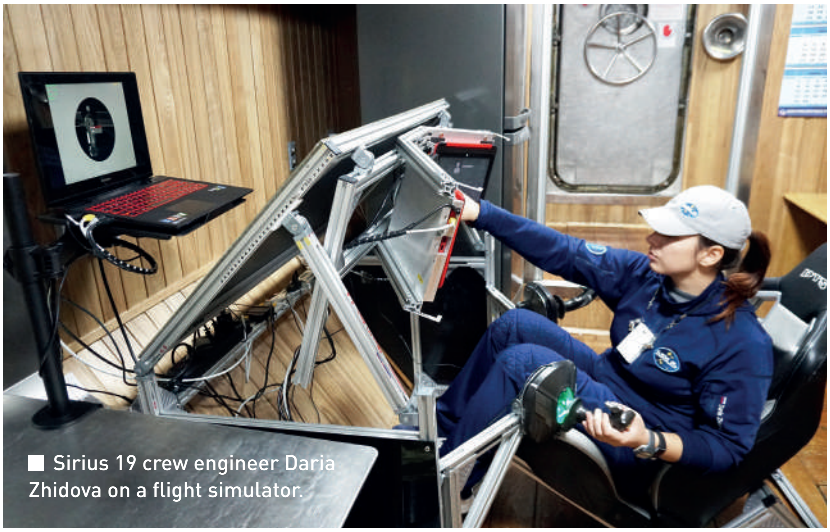
Developments are expected in expanding the possibilities of speech dialogue between human and robot, including the support of the emotional component of this dialogue. It is also planned to place the prototype R-Pod in a simulated space station experimental ground complex at the Institute of Biomedical Problems (IBMP) during the SIRIUS-21 one-year isolation experiment.

The R-Pod is designed as a complete product for audio-visual interaction with a crewmember through a multimedia system and a drive unit that implements the basic elements of emotional dialogue. The shape of the R-Pod's hull must be anthropomorphic and contain two functional modules: a body with multimedia system and two-axis suspension and a head with a flexible display screen. The demonstration screen should be able to display emotions in four colours and the R-Pod should function autonomously according to an uploaded program, while periodically receiving commands from the operator to correct and control actions. It must sustain a conversation and, in order to achieve more natural communication, must imitate typical emotions inherent in a live interlocutor. To ensure the necessary movement of the robot's head, two degrees of mobility are sufficient (nodding and turning the head).

The purpose of the multimedia system is to broadcast speech and sound information with the support of the basic elements of emotional dialogue, but the development of such a system is a very difficult task. Therefore, within the framework of this project we limited ourselves to consideration of two issues: development of a test algorithm for recognising elements of a typical dialogue; and support of these elements by graphical imitation of a typical emotion.

Both tasks should be solved with the help of the dialogue support unit and the R-Pod emotional support unit. The speech controller will have the following functions:

- choice of a response phrase in response to an astronaut's comment;
- screen control (display of basic facial expressions in accordance with the map of basic emotional states);
- swinging and turning the head of R-Pod in



■ Sirius 19 crew engineer Daria Zhidova on a flight simulator.

An important task of the project is the selection and development of software tools to support the dialogue between the robot and the crewmember

Speech signal processing

Dialogue between an operator and a robot can be divided into two modes based on different signal processing blocks:

- speech (based on dialogue support block);
- emotions (based on emotional support block).

The dialogue support block includes a speech database and a speech controller containing the following sub-modules: spectrum analyser; recognition unit; speech recognition module; and an automaton for executing speech commands.

The emotional support block contains the following modules: mimic database; module for synthesising the image of emotion; and colour indication module. The colour indication module is designed for colour support of emotion (colour saturation corresponds to the strength of emotion, for example red - anger, green - approval).

A dialogue system with a limited vocabulary was considered, where all possible types of dialogues and their classes are known in advance. Then the word recognition procedure is reduced to the classification of objects, i.e. the assignment of a priori known objects to a priori known classes. The formation of signs of individual words is carried out at the system training stage.

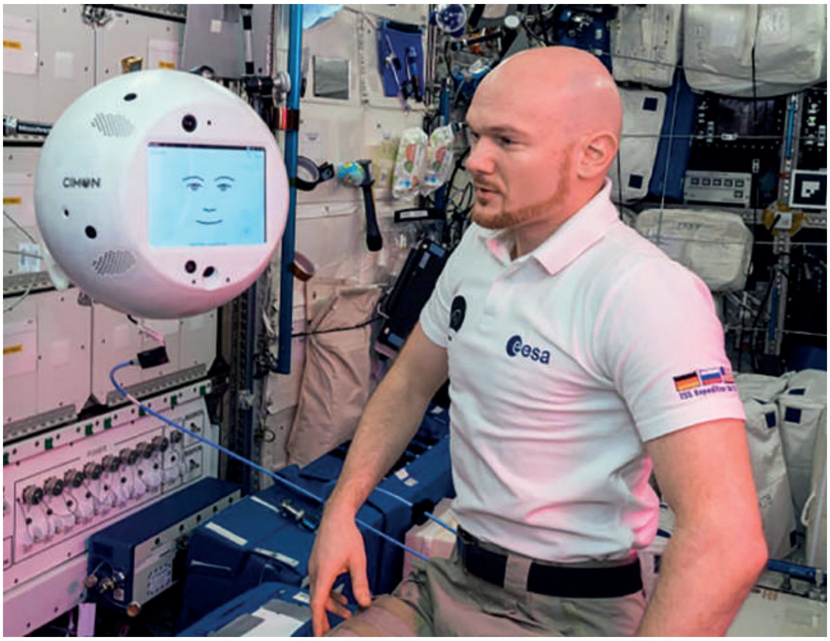
Most often, the formation of features is carried out directly by the recognition system developer or by a specialist who knows the specific task well. Currently, the following problems for all recognition systems can be identified:

- limiting the amount of data: systems are 'tuned' to a specific context by reducing the vocabulary and simplifying the language model;
- variations of the tempo and style of speech (mixed tempo, pronunciation of words, shouting);
- difference in the acoustic features of speakers (for example, the system is trained for adults and tested on children);
- spontaneous speech with overlapping (debates, arguments);
- speech recognition in conditions of interference (noise, reverberation).

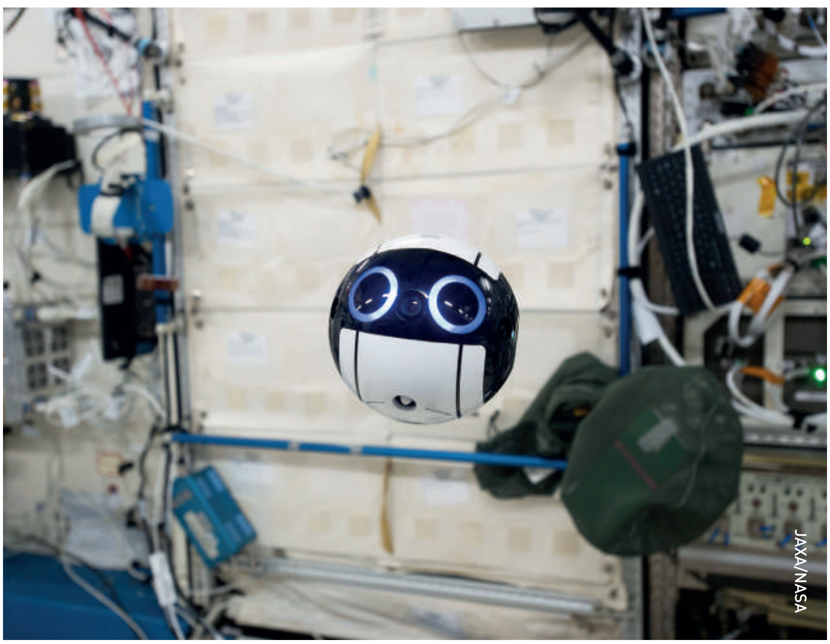
accordance with the response phrase;
- colour support for emotions in accordance with the basic emotional states map.

An important task of the project is the selection and development of software tools to support the dialogue between the robot and the crewmember, that is to organise a dialogue system that responds to every command of the user and, as needed, turns to them for information.

Traditionally, the development of such a system is based on the following components:



▼ Below: ESA astronaut Alexander Gerst interfacing with the Cimon robot on the ISS.



Bottom: JEM Internal Ball Camera on the ISS.

JAXA/NASA

- speech database;
- means of audio-visual recognition of emotions and speech;
- automaton for executing speech commands.

It was therefore decided to develop a speech database and an automaton system for executing speech commands and recognising emotions and speech (using the RobotStudio system created by Neurobotics). Based on the personal experience of imitating a space flight in the SIRIUS project and a long stay in isolation, a table of dialogues between the cosmonaut and the robot was compiled, as well as the reaction of R-Pod to voice commands in the form of head turns, illumination and emotion output to the robot screen.

In this project, we considered the possibility of constructing a vector of features of individual words based on an acoustic model. This solves the problem of preliminary processing of a sound signal and construction of a vector of features based on the phonemic representation of sound. In principle, the simplest algorithm for comparing words based on only seven criteria is capable of providing good recognition reliability.

Presenting emotions

The natural interface of communication between an astronaut and a robot can be implemented with the help of the robot's mimic apparatus which represents a complex of hardware and software tools to support speech dialogue and the emotional state of a human face. In general, the methods used to form the mimic apparatus are computer, optical, mechanical, solid-state and deformable. In accordance with the adopted psychology scale, six basic emotions are usually distinguished: joy, sadness, anger, surprise, disgust and fear.

The mimic apparatus of robots can be represented as a set of actuators with several stable positions, which should be clearly distinguishable. However, at present there are fundamental difficulties in imitating human facial expressions using the mimic apparatus of an

In accordance with the adopted psychology scale, six basic emotions are usually distinguished: joy, sadness, anger, surprise, disgust and fear

anthropomorphic robot, in particular due to the inability to reconstruct certain muscles of the human face (for example, the round muscle of the mouth, orbicularis oris). To simplify the task and solve the problem of simulating emotions by a robot, the only requirement for the reproduction of emotions is that they are reliably and easily perceived by a person.

Operational results

A draft design for a mobile portable robot was developed to be capable of recognising speech and providing psychological support to astronauts during a long space flight. During the development process, the block diagram of the R-Pod control system was determined and the parameters for the electric actuators were calculated, taking into account the existing loads and position requirements. After the choice of electric motors, a mathematical model of the drives was developed and the parameters of their regulators were calculated.

The R-Pod works in the following way. It starts in the waiting state, ready to receive commands. The crewmember voices a specific information request. As soon as the audio command arrives, the database provides information about the coordinates of the required audio information, movement of the robot's head, lighting and facial expressions. Then R-Pod issues an audio response along with certain lighting, facial expressions and head movements, after which the robot enters the initial waiting state.

The control system for displaying mimic images on the R-Pod LED display consists of a control computer with a video card, control software, controllers with receiving and transmitting cards and a set of interface cables. The video material is sent from the computer to the controller, where it is adapted to the display on the screen. In fact, the control system of the LED screen splits each frame of the image into many parts, and sends a corresponding fragment to each section of the LED display, which produces a complete image on a large screen.

Clearly, R-Pod is still in the research and development phase, but the development of a complex of software and hardware tools to provide psychological support for cosmonauts in orbit is seen as an urgent requirement for crewmembers. The correct solutions for the development of autonomous technologies, using sign language and elements of verbal communication, will assist spacefarers on long-term orbital space flights and, subsequently, the exploration of the Moon and Mars. ■

▲ Anne McClain with NASA's first Astrobee robot, named Bumble.

About the authors

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