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ABOUT THE CONCEPT OF USING ANTHROPOMORPHIC ROBOTS DURING HUMAN EXPLORATION OF THE MOON

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ABSTRACT

The paper discusses the different uses of anthropomorphic robots to meet the challenges of the Moon by human. It showed great potential of using such robots: to ensure the safety of astronauts, servicing a wide range of space objects, solving research problems in a non-deterministic environment.

In the formulation's part for the selection of specific embodiments of robotic systems are invited to consider the transport and manipulator's tasks separately. This formulation has allowed more specifically set goals for robotic systems and to synthesize their various combinations in the optimized composition.

Authors identified the most important problems of control systems development for space anthropomorphic robot; in particular, questions of inclusion in the robot control loop a human brain in relation to the lunar environment - in a copying robot mode on the lunar surface with the use of the remote operator and the exoskeleton. In addition, authors touched on learning and adaptation of the anthropomorphic robot.

The article proposed the concept of the use of anthropomorphic robots on the lunar surface, which takes into account the expected dynamics of the lunar infrastructure and manned lunar base.

Keywords: robotic system, anthropomorphic robot, Moon exploration, transport robot, manipulator, control system, extravehicular activity of astronauts, near-Moon habitat infrastructure, Moon base.

INTRODUCTION

An appearance of robotic systems (RS) for solving of Moon exploration tasks has very vague contours at the moment. It is connected largely to the absence of strict RS classification and fuzzy understanding of the tasks they will be carried out by means of the RS on the Moon. An even more abstractly the evolution of the RS on the Moon is represented in a relation to the achievement of certain exploration development phases.

The need for development of the Moon is recognized today by many space agencies. Most of them are considering the period of 2020-2030 as the beginning of the practical development of the Moon: first, using robots, then robots with humans. In contrast to the end of the 1960s, the Moon is considered today as the constant direction of technical intervention. Practical problems of development of the natural satellite of the Earth today mean a much more than demonstrate the possibility of achieving it. And, therefore, the RS should be established taking into account the long-term – strategic perspective.

Let us consider the use of the RS on the moon within the next 10-20 years. This is the period during which the planned real space missions and during which the creation of the desired image of the RS is a practical engineering problem.

TRANSPORT AND MANIPULATION ROBOTIC SYSTEMS

The choice of the type of robotic systems for lunar exploration tasks has no obvious answer because of the vagueness of many potential tasks. Therefore consider the potential tasks for a moon robot in more detail. ▪

All that can be called robotic systems, the most generalized in terms of the tasks being carried out by them, can be divided into two categories of systems: transportation systems and manipulation systems.

Implementation of transport functions – is the transfer of cargo and transfer of most RS (locomotion) from one place to another dislocation.

Performing manipulation functions - is to make complex actions with objects of artificial or natural origin, tools (by tools), etc., managing them, their position, their configuration and moving them within the manipulation region.

Of course, both the first and second categories of tasks will be required on the Moon. Therefore, we are interested, first of all, RS, combining the possibility of providing two categories of functions.

In some cases, RS may combine and transport and manipulation systems. An example is an anthropomorphic robot with two "arms" (manipulator) provided with “legs” (AR-600 [1], Petmen [2]), or wheel for the movement of the platform on the surface (Robonaut [3]). Widely known as non-anthropomorphic walking manipulators - SSRMS («Canadarm-2" Canada, [4]) and ERA (ESA [5]), it combining transport and manipulation functions. However, the listed examples were designed either for terrestrial environments or for work on board low Earth orbital station in zero gravity. For applications on the lunar surface applicability of these options it is necessary a separate consideration.

As part of the transport system variants of robot performance may be as follows:

flight vehicle - FV;

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- jumping robot - JR;
- ropeway - RW;
- rover wheeled robot/robot crawler - R;
- rail vehicle (displacement along a prepared track) - RV;
- walking robot ("feet") - WR;
- motion by means of manipulative actions (through reference points) - MA.

As part of the manipulation system variants of robot performance may be as follows:

- Cargo manipulator (CM) in which functions of manipulations with objects are mainly coming from transport mission;
- Anthropomorphic RS (ARS) – a manipulation system that is similar to a human cinematically and topologically;
- Technological manipulator (TM) – not anthropomorphic system of many kinematic chains (provides 5 or 6 degree of freedom more often, sometimes much more);
- Construction machine (CSM) in which manipulators provide a realization of some construction technological process and manufacture (welding, stitching, temperature rise, high pressure, diffusion etc.)
- Ground RS (GRS) – a system is for operations with ground and combines functions of manipulation with ground and its' transportation typically.

RS potential tasks are arranged into three types:

Type A – assistance and safety precautions of spacemen on the Moon,
Type B – service of space devices on the Moon,
Type C – investigation of research topics on the Moon and specifically in deterministic environment.

Represented types of tasks consider different levels of RS requirements for reliability and safety whereas potential emergency consequences are significantly different: it could be related to spaceman life, performance of expensive facilities or a part of research task failure.

If we tabulate expert review results of task types, versions of transport robots and robot-manipulators relating to usage environment on the Moon, we get the following results (see Table 1). Considering question experts make assumptions [6]:

1) Adaptability of specific RS release in the context of considerable types of task solving is measured in point scale: 2 – usage of this variant is preferable, 1 - usage of this variant is potentially possible, 0 - usage of this variant is not perceptible.
2) Non-equilibrium state of issues A, B and C are come into account in the integral estimation. For this purpose weight coefficients for issues A, B and C are 3, 2 and 1 respectively.
3) The additive model is in use for the integral estimation of RS adaptability.

Table-1. Integral adaptability result.

S Types	Variants of RS performance	Types of issue on the Moon			Total score (K_A*A+K_B*B+ +K_C*C)
		A*	B**	C***	
Transport	Flight vehicle (FV)	2	1	2	10
	Jumping robot (JR)	2	1	2	10
	Ropeway (RW)	2	2	1	11
	Rover wheeled robot/robot crawler	2	2	2	12
	Rail vehicle (RV)	2	2	1	11
	Walking robot ("feet") (WR)	1	1	2	7
	Motion by means of manipulative actions (MA)	1	1	0	5
Manipulation	Cargo manipulator (CM)	1	2	1	8
	Anthropomorphic RS (ARS)	2	2	2	12
	Technological manipulator (TM)	1	2	2	9
	Construction machine (CSM)	1	1	0	5
	Ground RS (GRS)	1	1	1	6

Note: *) – for issue type A the weight coefficient of supporting RS (K_A) is equal 3 (K_A=3);
**) – for issue type B the weight coefficient of supporting RS (K_A) is equal 2 (K_B=2);
***) – for issue type C the weight coefficient of supporting RS (K_A) is equal 1 (K_C=1).

As seen in Table-1, ARS has the highest integral adaptability result in providing functions for solving any types of issues. As for the providing transport functions R, RV, RW and FV have the maximal result. Thereby a development of ARS+R combination would meet the purpose of Moon exploration in the best way (in general).

Undoubtedly there should be another RS variants specialized on solutions for the more concrete technical issues.

ANTHROPOMORPHIC ROBOT-MANIPULATOR CONTROL SYSTEM IN THE CONTEXT OF OPERATIONS ON THE LUNAR SURFACE

In general there are three strategy of robot control: control by exoskeleton, supervisor control (human controller sets operating mode and controls a process with an opportunity to stop it only) and a full (completely self-sufficient operation without direct involvement of human controller).

It’s common in popular science (especially in fantastic fiction) to talk about completely self-sufficient anthropomorphic robots that could solve a problem on the run using artificial intelligence. However it’s been proved that it is impossible to create artificial intelligence or it would be identical to the natural human intelligence. At the same time it’s quite evident that present-day computer couldn’t yet compete with human brain performance as a source of immediate decisions or a unique bio-computer with constant updating of a new experience and permanent environmental analysis. That’s why an idea of human intelligence and muscular motor skills inclusion in the mobile object control system tract becomes a key point of perspective robotic science development as well as a high use of digital computers.

In that course of robotics development, called ‘bionic man-machine intelligence systems’, medicine achievements could be used to the full. It’s neuron-feedback based on bio-current detectors laid on muscles or implanted safely in human body.

As natural human intelligence is excelled artificial computer intelligence, as coping type of anthropomorphic robots exceed all other types of programme-controlled robots as far as supervisory in adaptability and flexible control.

However anthropomorphic robots as kind of coping robots has a fault: they could copy only those motions that master device makes by the moment.

The mentioned fault could be eliminated by adding special software of control, instruction and even self-instruction into the control system of anthropomorphic robot. In this case there is no need in necessary presence of operator with master-device physical and control could be exercised remotely from the very long distance as well as from Earth.

Integration of human intelligence into a robot control circuit, coping and programme-control modes sequencing let combine an execution of ‘accurate’ technological operations with ‘rough’ transport operations as well as operations of preliminary positioning and fixation at the work place.

It's necessary to use operation systems of rough real-time to enhance reliability and fail-operational capability [8]. Such a choice is conditioned be the huge risk of system problems. There is a variety of ready-made real-time systems that have the necessary qualities (VxWorks, LynxOS etc.). It's possible to use a few processors for the purpose of increase of effectiveness and fail-operational capability [9].

A robotic future directly depends on the development of two robot types that are successfully cooperate with a human: anthropomorphic configuration and ‘exoskeleton’ type. Herewith it’s effective to use adaptive tracker control system for both of robot types.

In anthropomorphic robot development for Moon exploration anthropomorphic and isomorphic principles should be strictly kept following geometric and kinematic scheme of human skeleton. With that an excess or descent of muscle ability and energy providing led to adaptability degradation and control system deviation. Alternatives to control are acceptable by a reason of inability to create tools for intellectualization. In this context zoomorphic robots ‘Monkey’ (DFKI, Germany [10]) and «Big-Dog» (DARPA, USA [11]) are well accord with modern technical opportunities for the beginning of Moon exploration by robots [12, 13].

For the purpose of control only scientifically grounded and really achievable methods of adaptable drivers’ control that are transferable to anthropomorphic robots could be used.

Next problems of equipment production and its' using in the open space should be solved before making a final choice of structure and design concept for anthropomorphic robot or strain exoskeleton:

- to synthesize a structure of controllers and motor drive circuitry in chains, to define a differential equation degree of follow-up system model, in other words quantitative and qualitative composition of proportional-integral-differential controllers (PID-controllers);
- to found a choice of element components: microprocessors, electromotors, control and connection interfaces, materials etc.;
- to develop a system of reverse force-torque reflection and the point is in corrective definition of programme-mathematical and hardware resources for control of force-torque data acquisition for the purpose of positive and negative circuit reentrancy formation;
- to set a synapses driving points and a quantity of them in the structure of controllers aimed to develop adaptive minor loop.

Until now some developers accept any follow-up control system with many different feedback sensors as an adaptive system. It is believed that with those sensors it would react for subject image, commands or external signals during technological operations processing and would work-off an error of deviation from target value, for example, coordinates, the position angles, speeds and moments. Upon those systems of computer vision, navigation, tactile, force-torque sensitizations and so on are identified as important.

However not a number and types of available sensors feature an adaptive tracking control system by the automatic control theory.

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To become an adaptive tracking system should be followed to make readjust structure of controller applying three well-known methods of linear adaptive control:

- the first method: a variation of so-called "Zeros" and "poles" constant coefficients values of the transfer function;
- a second method: a variation of linear differential equations order, basically they are a type of the transfer function;
- a third method: the introduction of synaptic inputs changing structural connection in the control system or the transfer functions "zeros" and "poles" numerical values.

Adaptation (accommodation) in nature is the body's adaptation to changing environmental conditions implemented by the biological variability and mutations within a species. In the control theory it is implemented by a change of the transfer function type.

The transfer functions of linear follow-up systems are described by fractional rational expressions. It's accepted to call a linear differential equation corresponding Laplace-image of the transfer function numerator as an input digital filter, and a linear differential equation corresponding to Laplace-image denominator - an output digital filter. The roots of the characteristic equations of the numerator are called 'input filter zeros' and the transfer function denominator – 'output filter poles.' The roots of the characteristic equations of the numerator are called "input filter zeros" and the transfer function denominator - "output filter poles."

Synaptic function, in fact, describe the learning process, i.e. the accumulation of "statistics" about the behavior of the object in the specific environmental conditions, collect and process the information about environment parameters changing.

The ability to change (adjust) the numerical values of "poles" and "zeros" discretely in time for some "rules" that depends on the parameters of the medium, and the first method is called a linear servo system adaptation to this environment.

The process of synaptic functions formation for numerical values of the roots setting (often heuristic or regression) called the analytical process of adaptive system learning. "Multivariate experiment" as a mathematical tool is used for the analysis of experimental data

Taken together the proposed solutions enable organically incorporate the human brain into a robot control system, bringing anthropomorphic robot possibilities to the capabilities of the person maximally.

The presences of force-torque feedback communication, adaptability of the system, self-learning capability are qualitatively distinguishing anthropomorphic manipulating systems from non-anthropomorphic. Therefore, even at the initial stage of the Moon exploration, before the manned flight into lunar space (the research mission is automatized), the use of ARS has great advantages.

THE CONCEPT OF ARS USE ON THE MOON

Let's consider the three phases of moon exploration:

Phase 1 – moon exploration by automatic vehicles.

Phase 2 – the human presence on the near lunar orbit (NLO) and landing on the short time on the other district of lunar surface.

Phase 3 – inhabitant lunar base creation on the concrete section of Moon. People visit the base periodically.

The necessity of RS use is evident on the all phases. The difference lies in current tasks. For example RS on the Phase 1 are used for:

- scientific equipment transporting on lunar surface,
- gathering a lunar rock samples,
- scientific equipment installation,
- specimen stacking in containers for physicochemical analysis, service for research platforms.

Base goal on the Phase 1 is transport. That is a scientific equipment transporting on long distance crossed (unstudied) region with use of rover, or with using a jumping robot or flight vehicles. Rope or rail way using is exigently for pioneer missions. ARS could be used by remote control from Earth with signal holdback about 2,5 sec for manipulation task. However their practical using is depend from carrying capacity of transport platform and powering vehicle in the whole. As already mentioned for securing full kinematic resemblance and adaptiveness antrop-amorphous system its dimension and power possibility should correspond to person. Therefore speak of delivering ARS can then, when possibilities appear delivering manipulation system with about 70 kg of mass and accordance for this on the Moon not less 2 kW. To the moment, when this possibility will be accessible, more rationally use technological manipulations (correspond decision we see on examples American Mars rover vehicles Spirit, Opportunity and Curiosity).

It's expected to use RS on the Phase 2 for:

- execution of preparation work on the surface for human landing,
- investigation of landscape and physicochemical analysis of rock,
- navigation equipment putting,
- ground clearing,
- human and scientific equipment transporting on the lunar surface, and all works from Phase 1.

Level of efforts for Phase 2 allow reckoning for that condition by ARS delivery and exploitation will be provide. If take into account possibility manipulating by ARS from near lunar orbit (NLO) (that is by in a practical manner absence holdback signal), ought wait, that exactness fulfilment ARS manipulation function will be maximum approached to the exactness human's arm on the Moon. It open perspective to redistribution part of work that should execute human on the Moon by the ARS. In given case effectiveness of human will be greatly more on the Moon, inasmuch as organize in a practical constant extravehicular activity (EVA) during a few 24 hours or a

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week impossible on the Moon, ARS using between extravehicular activity (EVA) and manipulating operator from the near lunar orbit (NLO) or from Earth can in much promote to decision such problem.

As for transport function supporting, using of platform like rover is quite obvious in given case enough. However that not only decision. Possible variants with FV (flight vehicle), JR (jumping robot), RW (ropeway).

It's expected to use RS on the Phase 3 for:

- preparatory building work of the lunar base,
- ground work,
- assembly work with modules for the lunar base,
- laying cable and the communications,
- distribution and service office equipment,
- control technical state of modules and open ground for securing receiving vehicles,
- after landing service freight and manned landing complexes,
- transporting modules and loads from landing place fundamental location,

and all works from Phase 1 and 2.

In this way the list and complexity works for the Phase 3 much excel work for Phases 1 and 2. Here practically all mentioned variants transport and manipulation systems will be claim (accordant with table 1). As for ARS, a peculiarity of using this system is that ARS could directly cooperate with human on this stage, what means a necessity of implementation safety system and efficient control environment situation besides control from side removed operator.

Taking into account a high manipulation possibility of ARS towards everything remaining type RS, particular interest introduce variant use ARS on ropeway (ARS + RW). This combination be represented very perspective in view of using RW provide low power (and labour intensity) on transport loads (including ARS) for lunar condition, ARS provide most exact manipulation operations.

Example of ARS+RW using:

1) Net supports and rigging arrangement fix on perimeter and radial direction of district the lunar base. Distance between supports can be considerable (to 5 km) in lunar condition.

2) ARS suspended on cable way and in such a way can moved along supports. Possible variant combination lifting bar ARS with rover for securing radius of action ARS outside cable way zone (that is variant with ARS+R+RW).

3) ARS can unhook from CW for securing possibility delivery to location of ARS with using that CW different loads (equipment, modules, GRS, CSM and other).

4) RW can used as electric communications for recharge ARS.

5) Combinations ARS, construction machine (CSM) and RW can be analogue of 3D plotter in scale the entire lunar base, using as main building material lunar regolith.

SUMMARY

1) ARS is a perspective robotic system for the lunar exploration goals practically from the beginning of exploration by automatic vehicles. It is necessary to distinguish robotic goals categories: transport and manipulation. ARS is positioned as a perspective manipulation system for Moon. With that a system is perspective for all phases of Moon exploration.

2) Rovers, jumpers and flying vehicles, cable way and rail truck are perspective as a transport RS on the Moon. Variants are enumerated in accordance with priority:

- Phase 1 (automatically Moon exploration) – R, JR, FV;
- Phase 2 (human presence on the NLO and short time landing on lunar surface) – R, JR, FV, RW;
- Phase 3 (creation of inhabited lunar base in concrete district of Moon) – R, RW, JR, FV, RV.

3) Other like full inclusion human brain in system of control by robot will be disturbed, which result to impossibility adaptability RS and its self-learning.

It's essential to follow a principle of maximum kinematic, energetic and force-torque resemblance to human when ARS is under creation. Otherwise a full inclusion of human brain in a system of robot control will be disturbed, what will lead to the impossibility of RS adaptability and its self-learning.

4) Relying on the combinative and expert analysis it's possible to make a conclusion that perspective combination of manipulation and transport robot systems applied to Moon are: ARS+R, ARS+JR, ARS+FV, ARS+RW, ARS+RV, ARS+R+RW.

CONCLUSIONS

Systematization of robotically systems (particularly transport and manipulation functions separation) and goals imposed on them allow to determine the most perspective variants of transport and manipulation RS combinations for each stage of Moon exploration.

Research shows that manipulation possibility of anthropomorphic RS and their advantages in coping mode by exoskeleton usage propel this robot type on the first priority level. Consequently a problem of robot development for lunar exploration acquires a concrete perspective of extension. Tomorrow's robots will obtain human characteristics but won't replace a man and still stay 'robots'.

CONFLICT OF OBJECTIVES

Authors corroborate that presented facts don't contain conflict of objectives.

CREDITS

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