RCL'S ADVANCED HIGH MOBILITY LOCOMOTION SYSTEMS FOR SPACE ROVERS AND SPECIAL ROBOTS

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ABSTRACT

This article presents advanced high mobility locomotion systems (LS), which were developed by RCL in the last 20 years in the framework of international projects with multinational participation of EU countries, Russia and other countries of the world.

About 50 successful projects were made during these years. RCL has developed, manufactured and tested a number of the advanced Locomotion Systems of the following types: spherical, rowing, hopping, wheeled, walking, tracking, wheeled-walking. They were jointly developed for and with Universities, Robotic Centres and labs in Australia, UK, Germany, Finland, France, China and Leading Space Agencies from EC (including ESA/ESTEC, DLR, CNES).

In this article we will present only LS for robots and rovers which are well known in the world, such as: Jarvis rover, HUT Rowing Robot, Polar Rover, walking-wheeled WoPa robot with two-arm manipulators and 32 DOF, Tracking RoSA-2, DLR Hoppers for asteroids, Robots for Nuclear Stations, CRFG iPartner Robot and LS mock-ups with 18 motor drives for ESA/ESTEC (ExoMader, ExoTER and MaRTA), which were developed jointly with ESA Planetary Automation Laboratory and delivered from RCL, St. Petersburg to ESA, Nordwjik during last 10 years.

In more details Russian and Chinese authors present the results of the current multi-country Robotic project iPartner, which was carried out by CRFG Consortium as cooperation of 4 international research Robotic teams from UVC/China, RCL/Russia, GIM/Finland and LOC/Germany. The project started in 2014, it will be done in 7 steps and will be finished in 2017.

1. INTRODUCTION

Since 1992 Science and Technology ROVER Company Ltd (RCL, St. Petersburg) had been carrying out joint works on advanced High Mobility Locomotion Systems for Space Rovers and Special Robots. RCL was founded as innovative company of VNIITransmash Institute. It was made in perestroika time by 15 key engineers, designers and experts from Space Robotic Department. Founders of RCL and consultants in the starting period were: Prof Dr. Alexandr Kemurdjian, Dr. Valery Gromov and Dr. Pavel Sologub who were Chief Designers for Locomotion System of Famous Lunokhods, Marsokhods, Chernobyl robots and rovers. From 1995 till nowadays the main RCL businesses are International Cooperation in the field of high mobility locomotion for robots and rovers including payload as well, special manipulators and 2axis stabilized platforms for mechatronics. This paper describes just main RCL international projects including excellent cooperation lasting more than 20 years with HUT/GIM Prof. Aarne team (Finland) and joint projects with ESA Automation Planetary Robotic Laboratories. Only in framework of the above two cooperation's more than 30 mock ups, models and over several hundred special motor drives were developed and delivered for acceptance tests.

2. THE PERIOD OF LUNOKHODs-1,-2 AND MARSOKHODs M94/96

Shown in this chapter is the experience of RCLs founders, consultants and specialists who were participating in these high level projects [1-5], Figure 1 flight models Lunokhod-1,-2 with mass of 756/ 840 kg and of speed 0.8-2.0 km/h for Space Moon Missions 1970 and 1973.

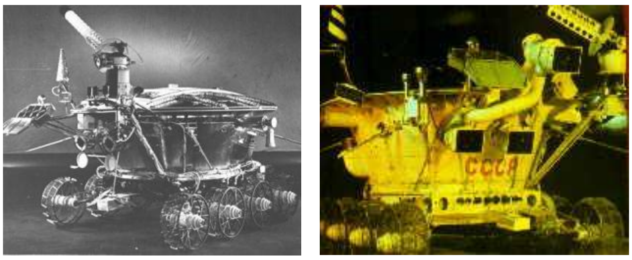

Figure 1. Flight Models Lunokhod -1, -2

The creation of "Lunokhod-1" is associated with the names of two remarkable scientists-designers: Korolev, S. P. and Babakin, G. N. The idea to create a Lunokhod came to Korolev in 1963. In September 1963 he addressed specialists of Mobile Vehicle Engineering Institute VNIItransmash with an offer to assess the reality of this idea. Tracking models for Lunokhods were developed with 2 and 4 tracks Figure 2.

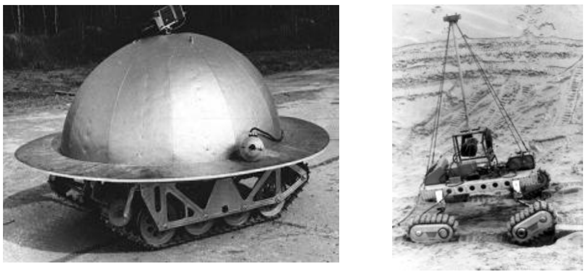

Figure 2. Tracking models of Locomotion systems

There were investigations of several locomotion systems [6] Figure 3 shows, what is better for moving on the Moon wheel or track.

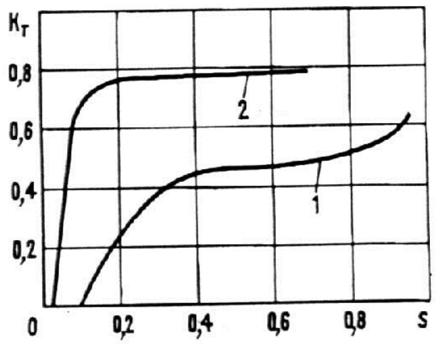

Figure 3. Traction coefficient slippage: wheel (1) and track (2)

Figure 4 shows flight models: first ski-walking Mars Rover M 73/75 (Mars 2 and 3 mission 1971) and Hopper Rover for Phobos investigation

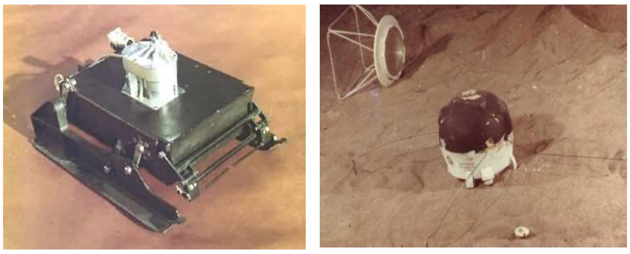

Figure 4. PROP-M (MarsRover M 73/75) and PROP-F (Fobos Hopper 88)

The first "Marsokhod" which had been completely developed by 1971 was the PROP-M mobile apparatus. It would be more correct to call it not "Marsokhod", but "Marsokhodik" (a small and funny Marsokhod) and, according to the today's terminology, a "microrover" would it be. So, the PROP-M was not just the first Marsokhod, but the first microrover too.

The mass of this apparatus amounted to 4.5 kg. The motion was performed by carrying the body with the aid of a pair of ski in turns (ski-walking mode of motion), and the cable communication with the landing station was provided. Aboard the apparatus two scientific instruments - dynamic penetrometer and radiation densimeter - were installed. The cable offered moving away as far as 15 m from the landing station.

In 1988 a descent vehicle, PROP-F, mass about 50 kg, was installed on the "Phobos-2" space station. According to the programme, the landing of this apparatus on the Phobos surface was envisaged in the following way. The "Phobos-2" station, on reaching Mars and being its satellite, executes several manoeuvres in changing the orbit, approaches Phobos at a distance of 50 m and throws the PROP-F apparatus on the Phobos surface. The PROP-F apparatus travels on Phobos's surface by jumps. At the moments when it stops a complex of scientific experiments is conducted. The mobile apparatus comprised instruments for investigation of soil, magnetic situation, temperature, local gravitation, etc. As is known, its gravitation is about 2000 times less than the terrestrial gravitation.

On the six-leg walking model NMHSA (Figure 5), an experimental check and development of the design of the walking propulsion system, control system was carried out. Installed on board the model installed on-board computer-control system, the system of "sensation", the overview and information system, the driver's seat. Each "leg" consisted of a bracket that was attached to a 6-gang frame, "hip" and "shin" with "foot". Hinges for carrying the "leg", flexing the "hip" and "shin" had electromechanical drives. The model had a mass of 750 kg, a speed of 0.7 km / h, a carrying capacity of 50 kg, a step length of 2 m, a maximum ground clearance of 1.5 m

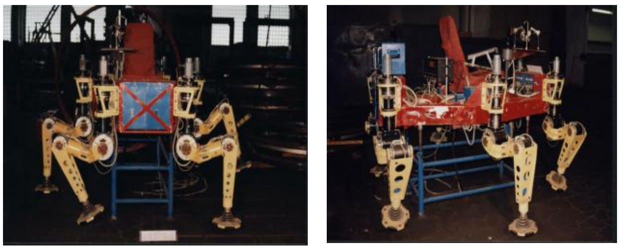

Figure 5. Locomotion system named NMSHA with 6 legs general view

Figures 6, 7 shows Chernobyl robot which was developed for cleaning roof of Chernobyl Nuclear station. This robot had mass about one tonne and speed 0.5 km/h [7].

Mars rover mock-up for Mars 96 Program named MIR (Figure 8) was a 3-section 6-wheeled vehicle with a Joint frame and with wheel-walking drive systems. A confident movement to the lifts in the wheeled mode is provided by cylindrical-shaped wheels, which form a developed support surface (practically along the entire breadth of the breadboard model). Rises with free-flowing soils and an angle of up to 34° were overcome in the wheel-walking mode.

Figure 6. Chernobyl Robot, STR-1

Figure 7. Chernobyl Robot works on Nuclear Station in 1986

The lack of ground clearance in conjunction with the hinged frame, which ensures constant contact of the wheels with the surface, virtually eliminates the danger of landing on the bottom when driving in a highly rugged terrain and areas with accumulations of stones. The hinged frame ensures the overcoming of ledges up to 1 m high, which corresponds in first approximation to the distance between the axes, while for conventional wheel drive schemes the height of the overhang is equal to the radius of the wheel.

An important advantage of the chassis is increased longitudinal and transverse stability due to the low location of the centre of mass. The weight of the model is 200 kg, the diameter of the cylindrical part of the wheel is 0.51 m, the base is 1.4-2.5 m. The high capacity of the chassis has made it possible to realize a new method of autonomous control of the movement of the planet-boat, based on the "sensing" of the undercarriage. That according to the information on the relative position of the chassis elements, the operating modes of the traction motors in the course of travel, dangerous obstacles are detected, for which the direction is automatically chosen according to the specified algorithm. As the tests showed, the "MIR" Provided a solution to the problem of automatic exit to a given point along the planned route with a minimum number of manoeuvres along the detour of a complex obstacle and without loss of mobility.

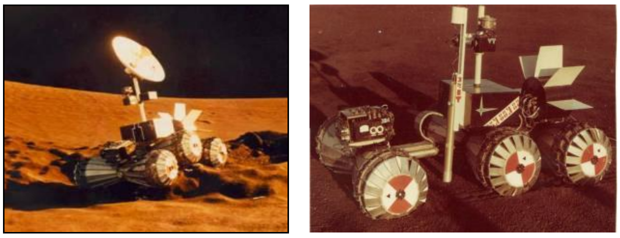

Figure 8. Mars rover mock-up for Mars 96 Programme tests on volcanos

Figure 9 shows the traction characteristics "Kt traction coefficient - S slipping coefficient" of Mars rover mock-up operating in wheeled and wheel-walking modes on cohesion less soil. The "Lunokhod's-1" chassis traction characteristic is shown here for comparison. The traction coefficient is defined as $\mathbf{K_T} = \mathbf{tg\alpha}$, where $\boldsymbol{\alpha}$ is angle of inclination of the slope surface surmounted. The slipping coefficient is defined as $\mathbf{S} = \mathbf{(L_1 - L_2)/L_1}$, where L_1 is a distance to be passed when moving without slipping; L_2 is a real distance passed.

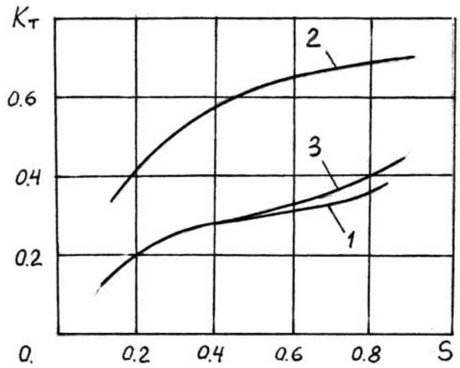

Figure 9. Traction characteristics of the Mars rover running mock-up (1, 2) and "Lunokhod-1" chassis (3) 1, 3 - wheeled mode; 2 - wheel-walking mode

The data presented show that wheel-walking mode has essential advantages as compared with wheeled one. The maximum value of the K_T coefficient in this mode corresponds to an angle of soil repose. The most effective robot turn from the point of view of power consumption is a turn at minimum wheel base.

3. INTERNATIONAL COOPERATION

Projects with FRANCE and GERMANY. From 1992 to 2006, RCL was one of subcontractor in Russia for Cooperation with France. RCL specialists participated in several projects of development of locomotion systems for demonstrators, robots and rovers: ADAM, IARES, LAMA, LOAN and COMARO, POLAR Rover which can be seen on Figures 10-14.

Figure 10. Robot ADAM on base Chernobyl robot STR1

These high mobility Locomotion systems were delivered and tested jointly with French Companies Matra Espace, Alcatel Escape and Laboratories of

SNRS/LAAS including Space Agency CNES. Concerning Multi-team cooperation Figure 14, it was made very well with CNRS/LAAS teams for France-Italian project Concordia/Polar Rover (Project Leader-prof Giorge Giralt) and Germany DLR Institute for Hopper Rover for Asteroid (Leader - Dr. Stephan Ulamec) [8].

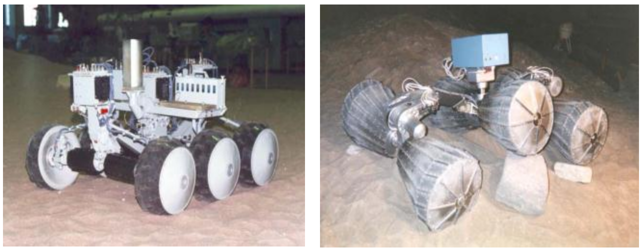

Figure 11. Demonstrators IARES and LAMA

Figure 12. Project LOAN on base of Marsrover M96

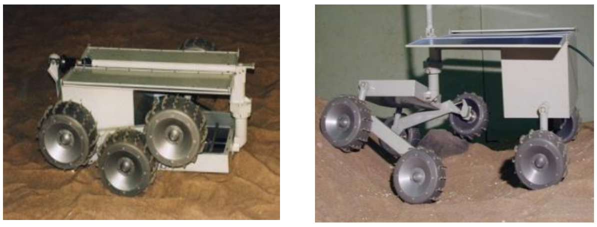

Figure 13. Project COMARO

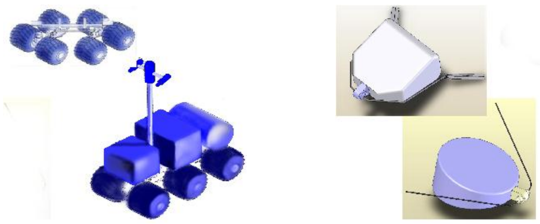

Figure 14. Polar Rover and New Hopper Rover for DLR

4. PROJECTS WITH FINLAND AND CHINA

During many years Science & Technology Rover Company Ltd (RCL) and Helsinki University of Technology (HUT) / Aalto/GIM had been carrying out joint works on development of mobile robots designed to operate on Earth and planets [9]. One of directions of these works is development of locomotion systems, which should provide high cross-country capability and maneuverability under the complicated environment. Terrain can have the complex relief, abundance of obstacles and soils with different bearing strength. This stipulates necessity to develop special locomotion system and control systems. The most original developments of the locomotion systems for mobile robots, performed by RCL and HUT jointly in a period of 1995-till present time. Results are presented in the figures 15-19

Figure 15. Test Rowing Robot

The oar-rowing locomotion system was developed as a version of the ecologically clean propulsive device for the pair-oar boat and rowing mechanism. These hi mobility Locomotion systems were delivered and tested joint with French Companies Matra Espace, Alcatel Espace and Laboratories of SNRS / LAAS including Space Agency CNES.

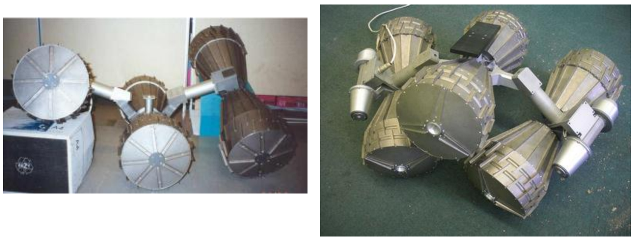

Figure 16. Jarvis rovers

Figure 17. RoSA-2

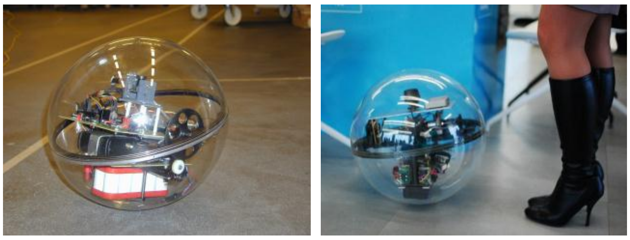

Figure 18. Spherical Robots General view on Exhibition

They were made by order of European Space Agency (ESA), within the framework of the proposal to tender on development of a micro-robot for scientific applications, as well as for operation in forestry and public service. Each development was finished with creating and testing the full-sized mock-up taking into account requirements on a robot's mass, overall dimensions, power consumption and control system. The Chapter gives description of the ball-shaped, rowing, wheeled, wheeled-walking, track and walking locomotion systems.

Figure 19. Work-Partner Robot with 32 DOF

Figure 20. Two-arms Work-Partner Manipulator

Cooperation with China developed in the direction from the Moon rover demonstrator to iPartner robot [10, 11]. It is shown on Figures 21.

Figure 21. Moon Rover demonstrator and iPartner

iPartner robot is current multi-country Robotic project, which was carried out by CRFG Consortium as cooperation of 4 international research Robotic teams from UVC/China, RCL/Russia, GIM/Finland and LOC/Germany. The project started in 2014, it will be done in 7 steps and will be finished in 2017.

5. ROBOTIC WORKS FOR NUCLEAR STATION

Figure 22 shows a robot capable of carrying out work after a fire.

Figure 22. Robot for fighting fire and clearing debris after a fire

The Figure 23 shows a robot for monitoring radiation hazardous production and conducting repair and evacuation work. The robot's peculiarities are an effective manipulator, the security of the equipment and quick-detachable caterpillars which can be easily deactivated.

Figure 23. Robot for monitoring radiation hazardous production

6. PROJECTS WITH ESA/ESTEC

Many years RCL has joint works with ESA Planetary Automation Robotics Laboratory of ESA/ESTEC.

These are in the field of scale planetary models for high mobility locomotion systems with special ultra-light manipulators and PTU which ESA/ ESTEC uses in laboratory tests in framework of ExoMars rover program or others missions.

This excellent cooperation started from projects ExoMars09 ESA CDF Study Report, Ref. CDF-14(A), ESROL ExoMars09 rover, ExoMaDER and at the moment it continues as well for projects ExoTER and MaRTA models . [12,13,14,15]

RCL team thanks very much ESA Robotic Laboratory specialists: Michel van Winnendael and Gianfranco Visentin, Pantelis Poulakis and Martin Azkarate, Martin Zwick and others colleagues for fruitful cooperation.

Figure 24 shows some a tests of Exoter and Marta rover models which were developed in the last years, i.e. 2014-2017.

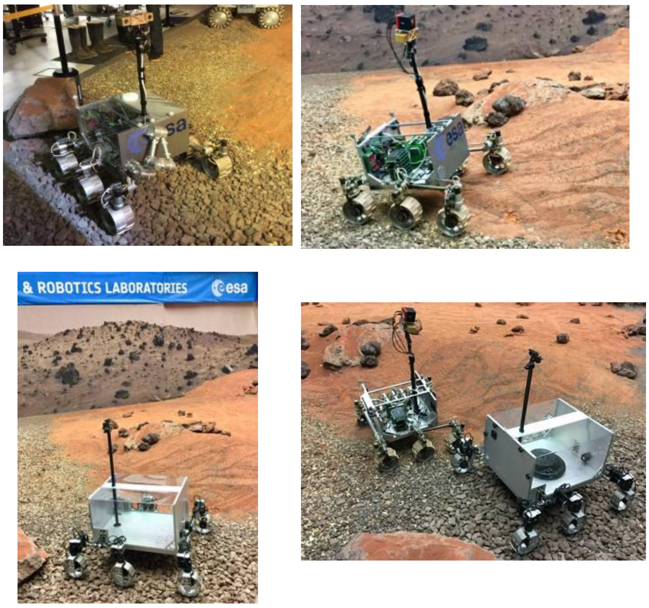

Figure 24. Test of ExoTER and MaRTA rover models

7. PROMISING PROJECTs

RCL does not stop at the achieved results and continues research in the field of applied robotics. Figure 25 shows a small-sized robot with a spherical shape of high cross-country capability, capable of being transported to a remote distance.

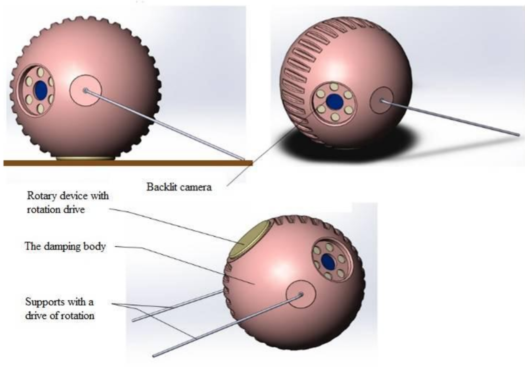

Figure 25. A small-sized robot of spherical shape (concept)

This robot can be equipped with video cameras, microphones and radio monitoring systems. Groups of such robots can form a multi-agent group, which gives the system a number of fundamentally new properties and capabilities.

The formation of a complex multi-agent system (figure 26), consisting of simple components, leads to the creation of systems that have the following most important features: increased reliability (the loss of some of the members of the collective does not affect the performance of the entire system as a whole); flexibility (the ability of the system to reconfigure); the potential for the development and complexity of the tasks to be solved by increasing the capacity of the team. Modern applications of using the collective behavior of robots (physical, non-software) are very multifaceted: the teamwork of robots jointly performing diagnostics of hard-to-reach objects; monitoring of the environment; collective solution of problems by robots-rescuers; reconnaissance and reconnaissance (for unmanned aerial vehicles, military robots); Security functions, patrolling, etc.

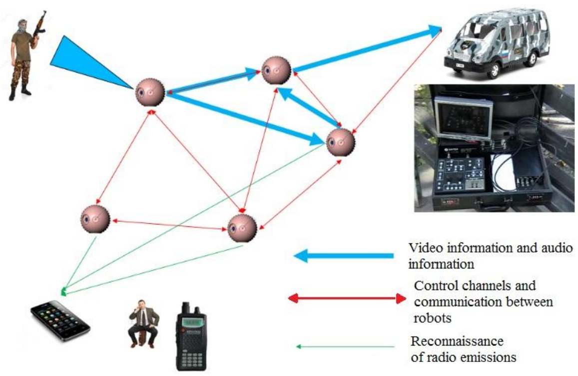

Figure 26. Multi-agent group of spherical robots

Work is actively carried out to design robots for the diagnosis of pipes of various diameters, stabilized platforms for cars that provide driving without crew, a multi-component robotic multi-agent system including ground, air, surface and underwater based robots has been developed and patented.

Completed research in the field of precision positioning of robots based on satellite navigation systems, local radio navigation systems with the addition of their inertial systems and systems using data from video cameras and LIDAR's. Navigation with the addition of their inertial systems and systems using data from video cameras and LIDAR's.

8. CONCLUSIONS

Thus, today RCL is an organization that has undergone a long way of development in the field of designing planet-walkers and remote-controlled machines. The RCL staff make it possible to realize the accumulated experience and the existing extensive backlog at a modern technological level. RCL is open for cooperation and ready to participate in new projects.

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