JOINT RCL & HUT DEVELOPMENTS FOR MOBILE ROBOT LOCOMOTION SYSTEMS DURING 1995-2002

A. Bogatchev (1), V. Koutcherenko (1), S. Matrossov (1), S. Vladykin (1), V. Petriga (1)
A. Halme (2), J. Suomela (2), I. Leppanen (2), S. Ylonen (2), S. Salmi (2)

(1) Science & Technology Rover Company Ltd (RCL)
Russian Mobile Vehicle Engineering Institute (VNIItransmash)
2 Zarechnaja Street, 198323, St. Petersburg (Russia)
rc@rcl.spb.su, rover@peterlink.ru

(2) Helsinki University of Technology, Automation Technology Laboratory
PL5400, 02015 HUT (Finland)
aarne.halme@hut.fi, jussi.suomela@hut.fi

INTRODUCTION
During many years Science & Technology Rover Company Ltd (RCL) and Helsinki University of Technology (HUT) carry out joint works on development of mobile robots intended to operate on Earth and planets. One of directions of these works is development of locomotion systems, which should provide high cross-country capability and manoeuvrability under the complicated environment. Terrain can have the complex relief, abundance of obstacles and soils with different bearing strength. This stipulates necessity to development 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 1995-2002 are presented in the paper. 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 paper gives description of the ball-shaped, rowing, wheeled, wheeled-walking, track and walking locomotion systems.

LOCOMOTION SYSTEM DEVELOPMENTS

Ball-shaped robot.

This robot was developed within the framework of the proposal No. ARS-4/96 in response of ESA Invitation to Tender AO/1-3094/96/NL/JG on Mars rover. Some modifications of the robot were made in the process of work with the object of increasing its reliability and effectiveness of operation. In all ten breadboards were manufactured during 1995-2002. According to the last version the ball-shaped robot (IDU-5) consists of the ball-shaped transparent cover from two halves connected together with an equatorial rim and the internal driving unit (IDU) of the ball hanged from the rim (Fig.1) [1]. The robot is moved with two motors. The energy source is a NiCd battery, which provides autonomy of several hours. When the rim is rotated about the X-axis (Fig.2, Fig.3) the rim and the ball rotate to the direction of the IDU. When the rim is rotated about the Z-axis and the rim plane is in horizontal position the heading of the IDU change.

Fig.1. Ball-shaped robot

Fig.2. Functional principle

Fig.3. 3D model of IDU-5
The driving force is generated by means of the gravitational moment generated by the IDU when driven by its one of the motors. Controlling the speed of the drive controls the speed of the robot.

The robot has the following advantages:
- cannot be overturned;
- can clear easily collisions;
- easy to make resistant to the hard environment;
- very high energy efficiency in locomotion when rolling resistance is moderate.

The motion capabilities (moving uphill and overrunning obstacles, soft terrain) are optimised when the mass of the cover is small compared to the mass of the IDU, and the mass centre of the IDU is as low as possible.

For visual and audio perception the robot is equipped with a camera and a microphone and video link. The transparent cover makes it possible to use the camera and other optical devices inside the ball. The communication to the control station is done with a radio modem. The robot is equipped with a micro controller board and has sensors for temperature, pan, tilt and heading of the IDU. Scientific apparatus for study, for example, the properties of surface can be mounted as well. All equipment are mounted on the same platform that is used for the IDU.

The ball-shaped robot principal technical data are the following:
- cover internal diameter, mm: 240/300
- maximum mass / IDU mass, kg: 3/1.5
- speed of motion on an even horizontal surface, m/s, no less: 0.5
- supply direct voltage, V: 12
- capacity of a storage battery, A h: 1.5

**Track locomotion system for the micro robot RoSA-2.**

This locomotion system was developed as a platform for the Drilling and Sampling Subsystem (developed by HUT in cooperation with Space Systems Finland and VTT Automation) performing deep (up to 2 meters) soil sampling on the surface of Mars or other planetary objects [2]. This work was performed under ESA contract called “Micro-robots for Scientific Application 2" 1999-2000. Fig.4a,4b shows a photograph of the rover. The locomotion system is intended to transport a payload as well as to move the drilling unit (the part of the payload) in the vertical direction while preparing the drilling process and when unloading the soil samples.

The locomotion system consists of the body; two tracks (Fig5); mechanism for vertical displacement of the drilling device, consisting of a drive and levers; drive for rotating the drilling device; tether unit consisting of cable reel, cable and cable dog.

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Fig.4. Micro-robot ROSA-2

Fig.5. Track drive
The track drives are placed in the track units, and contains the motor, gear head and horizontal screw which engages into mesh with ball-bearing mounted on the track (Fig.5) The screw moves the track when operating the drive. The robot is commanded and supplied with power from Lander via a tether (Fig.6a,6b).

The rotation of the drilling device allows drilling/sampling at angles ranging from the vertical to the horizontal. The body lifting ensures adjustment of the rover’s ground clearance. This feature significantly improves the locomotion system cross-country capability.

The locomotion system has the following main characteristics:

- Maximum motion speed on the horizontal surface, m/h: 60
- Mass of chassis/payload mass, kg: 5/7
- Overall dimensions (LxWxH) in stowed position, mm: 400x400x110
- Slope climbed (with minimum clearance), degr.: up to 30
- Obstacle surmounted (with minimum clearance), mm: 60 (height)
- Cable length, m: 40

**Wheeled chassis JRover for the planetary rovers.**

RCL and HUT developed this locomotion system in two versions. The first version was made without mechanisms for walking (JRover-1,1997) in order of the Monash University, Australia [3,4,5]. The second version was made with mechanisms for walking (JRover-2,2001). JRover-2 is a small chassis of the Russian Marsokhod-96 type. General view of JRover-2 is shown in Fig.7a, 7b. [6].
The purpose of the chassis is tests of control systems, navigation, scientific payload, etc. for both planetary rovers and autonomous robots when moving over the terrain with hard relief and soil conditions. J Rover-2 was designed in the configuration of the six-wheeled sectional chassis of high cross-country capability developed for the Mars rover at VNIITRANSMASH [3,4,7]. Principal elements of the chassis are the wheel-walking propulsive device (wheel arrangement is 6x6), articulated frame and cylinder-cone-shaped drive-wheels installed in pairs and occupied practically all the chassis bottom. The chassis with the minimum wheelbase practically does not have a ground clearance that allows moving over the rocky terrain.

The drive-wheels of the front and rear axles are mounted on the ends of levers able to rotate forward/backward with the mechanisms for walking installed on the frame. At the same time both axles can rotate about the robot longitudinal axis (two longitudinal hinges). The central free hinge ensures rotating the semi-frames about axes of the middle drive-wheels (the transversal hinge). As result the constant contact between wheels and surface unevenness is ensured (adaptive chassis). All the chassis drives are provided with parking brakes. Each of the chassis section has the platform for blocks of the control system and scientific equipment. Power sources (Ni-Cd storage batteries) are placed inside the drive-wheels that lower the height of the centre of gravity, and, consequently, improve stability of the robot to overturning [8]. There are two modes of the chassis motion: wheeled mode and wheel-walking mode. The wheeled mode is realized with the different constant wheelbases resulting by conditions of motion. Turning the chassis is fulfilled on the spot or using the “tractor type” turning. The wheel-walking mode used under complex soil conditions and when going up a steep friable soil slopes. This mode is realized with the drive-wheels and mechanisms for walking. The sequence of their operation is shown in Fig.8.

Fig.8. Scheme of motion in the wheel-walking mode
1-initial position; 2- first axle movement; 3- middle axle movement;
4- rear axle movement; ●-operating drives of the wheels and mechanisms for walking; ○-no-operating (braked) drives; l-chassis displacement for one step
Tests have shown the wheel-walking mode ensures climbing loose soil slopes of 30 to 32 degrees (angle of repose). These slopes are not surmountable in the wheeled mode nor by any tracked vehicle. The chassis is equipped with position sensors in the hinges, which give information about mutual position of the chassis elements relatively each other. Velocity-type encoders measure rotation speed of the driven wheels and motion speed of the wheel axles in the wheel-walking mode. These sensors are necessary for autonomous robot control system.

The JRover2 has the following principal parameters:

- Mass of chassis, Payload mass, kg: 30/30
- Dimensions (length x width x height), m: Variable: 0.8-1x0.65x0.4
- Step length, m: 0.1
- Drive:
  - Motor: Maxon DC motor RE 118798, d=36 mm
  - Gearhead: Planetary gearhead 110407, d=42mm
- Drive number: 8
- Position sensor in hinges and mechanisms for walking:
  - Type: Potentiometer
  - Resistance, Ohm: 4.7
- Motor velocity-type transducer: Digital encoder HP HEDS 5540
- Motion speed on a horizontal rigid surface, km/h: 1.2
- Storage batteries capacity, Ah: 0.7
- Obstacles surmounted:
  - Loose soil slope, deg: 20/30-32 (angle response)
  - Wheeled mode/ wheel-walking mode:
  - Separated rock (height), m/vertical obstacle, m: 0.35-0.55/0.35-0.55

Walking locomotion system Hybtor for the mobile service robot WorkPartner.

WorkPartner is the prototype of a lightweight mobile service robot designed to work interactively with humans in outdoor environment [9,10]. It is intended to operate in a forest, park and to perform the works related to transportation and cleaning industry and streets of towns. Therefore the locomotion system must provide a possibility for the robot to move over the uneven outdoor terrain, capability of moving in sand, swamps, snow and rocky grounds. The robot is equipped with a two-hand manipulator system (can handle loads up to 15 kg). The arm gripper can be replaced by a working tool, like a cutting tool. The on-board power system includes a combination of as mall lightweight combustion engine wit generator and batteries.

The locomotion system was developed in the form of the platform called as Hybtor or Hybrid tractor (Fig.9, Fig.10).

To provide high cross-country capability for robot the platform consists of the walking propulsive device and articulated frame with the active hinge. The propulsive device has four legs similar to mammals’ legs in which drive-wheels are installed instead of the foot. The platform ensures three modes of motion: wheeled mode, walking mode and wheel-walking mode. Wheeled mode...
enables the robot to move with speed of 7 km/h. In the walking mode the wheels are locked and locomotion uses the legs only. This mode is intended for motion on the uneven terrain when moving speed is lower than 5 km/h. Wheel-walking mode is combination of these two modes. The leg movement is performed with the leg drives and drive-wheels, being in the constant contact with the surface, ensuring the stability for the robot. At the end of the leg movement stage the drive-wheel is blocked. Depending on soil properties, a robot motion when one side operates, for example, in wheeled mode and another in walking one may appear to be effective. The leg drives of the platform are identical. Each of them consists of a Maxon EC250W 48V motor, a tailor-made gear and a ball crew.

Main parameters of the platform are the following:
- Dimensions (length x width x height), m 1.4x0.4x0.5-1.2
- Motion speed on a horizontal rigid surface, km/h 7.0
- Mass, kg 200
- Payload mass, kg 60

The control system hardware consists of four micro-controllers (Siemens, one for each leg), and industrial pc104 Pentium processor as the main computer, and a CAN-bus, which connects all of them. The micro-controllers control the drive motors through a drive electronics specially designed for EC-servo motors. The software is being developed under QNX real-time operating system.

WorkPartner is a long-term research and development project started in 1998 and planned up to 2005.

**Oar-rowing robot (Robotics boat).**

The oar-rowing locomotion system was developed as a version of the ecologically clean propulsive device for the pair-oar boat and rowing mechanism (Fig.11a,b).

![a) general view](image1)

![b) oar driving mechanism](image2)

**Fig.11. Oar-rowing robot**

In this case the accumulated experience of developing the locomotion system with legs is used. In essence the oars mounted on the boat operate as when hand rowing. Locomotion system consists of the special drive mechanism providing 4DOF for each oar and computer control system[11,12]. From the point of physic process the operation of the oars corresponds to operation of the legs with distinction that body does not take support on them but on the supporting media (water in this case). Tests conducted confirmed the serviceability of such locomotion system.

Main technical data of the oar-rowing robot:
- Boat type Small standard 4 m rowing boat
- Mass without equipment 70
- Total mass with equipment 210
- Velocity (calm water, mass-285 kg), km/h 1.8-2.0
CONCLUSION

The locomotion systems developed jointly by Russian Rover Company Ltd (RCL) & Automation Laboratory of Helsinki University of Technology (HUT) can be used when creating mobile robots for utilization both on planets and on Earth subject to their purpose, environment and technical requirements on cross-country ability and control systems. Application original propulsive devices provides high cross-country ability and maneuverability under complex conditions (relief, soil, slopes), that expands possibilities for scientific investigations. Accumulated experience can be used to develop mobile robots.

REFERENCES