Reconfigurable Autonomous Wheel-Tracked Robot

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***Abstract*—The article describes the results of research of a new transport robot type with enhanced functionality due to the possibilities of overcoming various obstacles as well as high-speed motion along even surfaces by reconfiguring its structure to a kind of the motion surface. The robot allows automating various types of work in zones of increased danger to humans and in hard-to-reach areas. The robot has two tracked drives located on the technological platform sides, and two wheel drives mounted to the front and back parts of the platform between the tracked groups. The axles of the wheel drives are connected with the platform by means of levers. The robot has wide opportunities to move over rough terrain as well as to overcome the obstacles of various shapes, including obstacles with a height greater than the height of the tracked groups. A kinematic model of the robot has been developed for the study of various modes of robot movement. The experimental model with a remote control based on standard components has been implemented. The efficiency of the experimental model was tested with remote manual control over the radio channel. The system stability was evaluated by program methods. The simulation and experimental results are given.**

Keywords—automation, autonomous robot, reconfigurable design, off-road locomotion, emergency work, measuring system, simulation.

I. INTRODUCTION

In emergency situations, for example, in case of fires or during hazardous operations, such as demining, it is necessary to deliver appropriate technological, inspection or rescue equipment to the working area in automatic mode [1, 2].

A convenient solution to the problem is the use of autonomous robots that have specified equipment on board [3]. Designs of autonomous transport platforms for work in unstructured environments were considered in [1]. There are robots for use in emergency situations with tracks and a platform with installed onboard equipment [4]. An all-terrain electric track board and an off-road locomotion robot were described in [5, 6]. These robots have the ability to move in unknown or off-road conditions but cannot overcome some obstacles, in particular, comparable to the height of the track groups, and are not able to move along steps of stairs flights. Due to the lack of reconfigurable wheels, they have a low speed on smooth surfaces that is often necessary for the independent rapid motion of the robot from the place of disposition into the work area along highways.

Problems of control and navigation of such systems were considered in [7-12]. A necessary part of control systems of autonomous robots are sensors for monitoring external and internal parameters [13-18]. Issues of the autonomous robot simulation are presented in particular in [19-22].

In contrast to the known solutions, the considered design and control of the robot allow moving through various types of surfaces, including the urban environment, where it is necessary to overcome obstacles of a complex configuration, such as flights of stairs. The robot can move on flat surfaces at the speed exceeding the speed of robots equipped with tracked-type drives. It also allows saving the life of tracks that are subject to wear while driving on solid surfaces such as asphalt or concrete. At the same time the highways themselves are not damaged.

The robot has wide opportunities to move over rough terrains as well as to overcome obstacles of various shapes, including obstacles with a height greater than the height of the tracked groups.

II. DESIGN OF THE ROBOT

The proposed design of the robot contains a combined drive system consisting of transformable tracked and wheel groups (Fig. 1).

The robot has two tracked drives located on technological platform sides, and two wheel drives mounted to the front and back parts of the platform between the tracked groups [23].

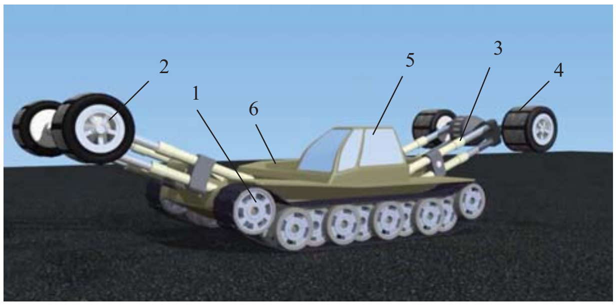

Fig. 1. Design of the robot 1 – tracked group, 2 – wheel group, 3 – telescopic levers, 4 – extending parts (spikes), 5 – onboard control system, 6 – technological platform

A peculiarity is that the axles of the wheel drives are connected with the platform by means of levers. The lever drives are placed on the platform with the possibility of moving the wheel drives vertically relative to the platform. A lever length can vary that allows transforming the robot to overcome various obstacles. There are extending parts on the wheels that have a form of spikes. This solution increases a diameter of the wheels and its passability.

A kinematic model of the robot in the *SolidWorks* environment has been developed for the study of various modes of robot movement. The motion on a flat surface is carried out only by the wheel groups with retracted spikes and raised tracked groups. That provides increased speed in this mode (Fig. 2a).

The motion along an uneven surface is carried out only by the track groups (Fig. 2b). The wheel drives are raised in this mode that provides increased passability.

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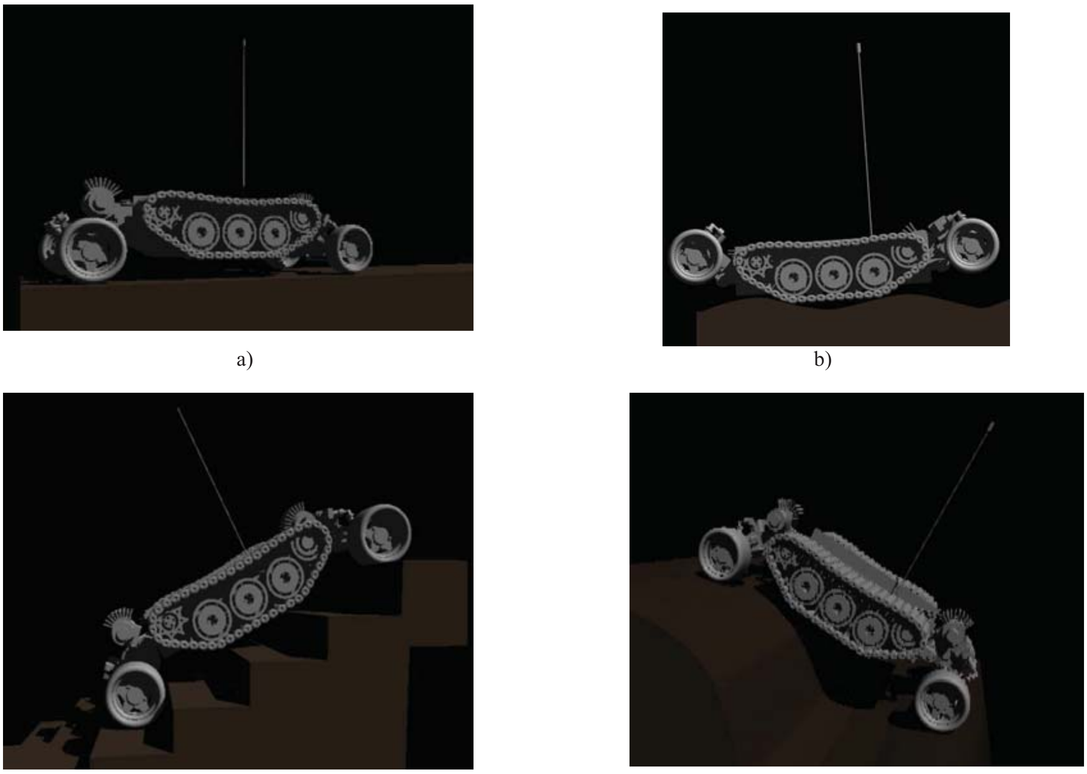

a) b) c) d)

Fig. 2. Robot motion modes for various kinds of surfaces a) flat surface, b) uneven surface, c) flight of stairs, d) complex obstacle

Flights of stairs and obstacles of complex geometric shape can be overcome by simultaneous use of the wheel and tracked groups. Positions of the wheel groups are changed relative to the tracked groups.

The length of the levers and the height of the wheel spikes are determined by sizes and shapes of stairs and obstacles (Fig. 2c, 2d). The results of kinematic simulation showed the possibility of the robot to overcome all these types of obstacles.

III. ROBOT CONTROL SYSTEM

The robot control system allows automatic mutual position reconfiguring the tracks and the wheels that depends on road and obstacle features. The obstacle features are measured by means of obstacle height sensors, obstacle width sensors, sensors of the platform angle, obstacle distance sensors, and sensors of presence of the next upper and lower step on stairs flights.

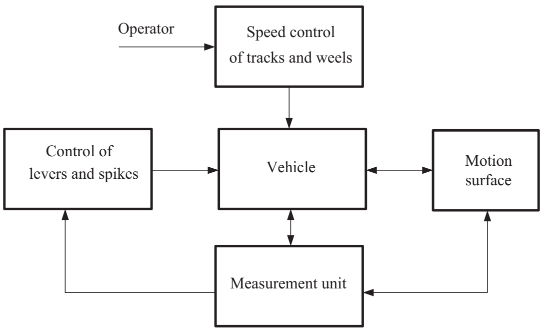

Fig. 3. Robot control system

Fig. 3 shows a structure of the control system. The controlled object is the robot platform with technological equipment.

The speed control unit of tracks and wheels sets the corresponding speed values programmatically or remotely upon a command from an operator.

A measurement unit has sensors to collect information about external conditions, converts it and sends to the levers and spikes control unit. This unit reconfigures robot parameters in accordance with this information, i.e. controls the inclination and the extension of the levers as well as the length of the spikes.

A structure of the measurement unit is shown in Fig. 4. It contains obstacle width and height sensors, an obstacle distance sensor, a platform tilt angle sensor, and step presence sensors.

Information from sensors about a position of the robot and the obstacles goes to the controller. It processes this information and sends corresponding signals to the drive system to change lengths and tilt angles of the levers and lengths of the spikes.

IV. EXPERIMENTAL MODEL OF THE ROBOT

The experimental model of the robot is its reduced copy made on the basis of standard components, namely, the wheel group and the tracked group with built-in drives. It is controlled from a remote control unit.

General view of the experimental model is shown in Fig. 5. The overall dimensions of the model in the position shown in Fig. 5 are: 500 mm length, 250 mm width and 170 mm height. The wheel group can change the length and the height of the model accordingly while moving. The drive control unit of the each track includes an asynchronous motor controlled by a frequency converter. Speed feedback is based on a tachogenerator located on a motor shaft.

The signal from the tachogenerator is fed to the inputs of an ADC. Then it goes to the speed control unit of the tracked group in a digital form. The speed control unit is built on the basis of a comparator and a digital controller.

Usage of the regulator in the system allows compensating speed change that is correlated with the torque change of the motor shaft. As the torque increases, the rotation speed decreases.

The controller adjusts the control signal so as to maintain the speed at a constant level while monitoring the maximum possible frequency of the alternating current supplied to the drive.

DC motors with protection against an overload and a short circuit are used in the drive lever.

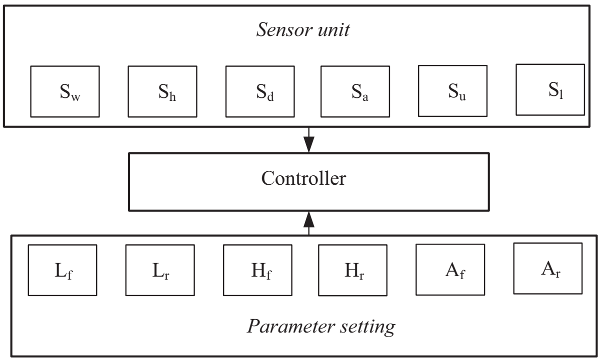

Fig. 4. Structure of the measurement unit. S_w – obstacle width sensor, S_h – obstacle height sensor, S_d – obstacle distance sensor, S_a – platform tilt angle sensor, S_u – upper step presence sensor, S_l – lower step presence sensor, L_f – front lever length, L_r – rear lever length, H_f – height of front wheel spikes, H_r - height of the rear wheel spikes, A_f – angle of the front lever inclination, A_r – angle of the rear lever inclination

Signals from optical sensors determine an inclination angle of the levers. They are converted to the digital form using an ADC. An algorithm for the required control signal is implemented in the program for the inclination angle and the lever length calculation.

Efficiency of the experimental model was tested with remote control over the radio channel. The test showed that the robot fulfills all motion modes including the motion up and down the stairs.

V. SIMULATION OF LEVERS EXTENSION CONTROL

Simulation of levers extension control was performed in the *Simulink* application of the *Matlab* software package using the appropriate standard blocks to analyze functioning of the full-scale robot.

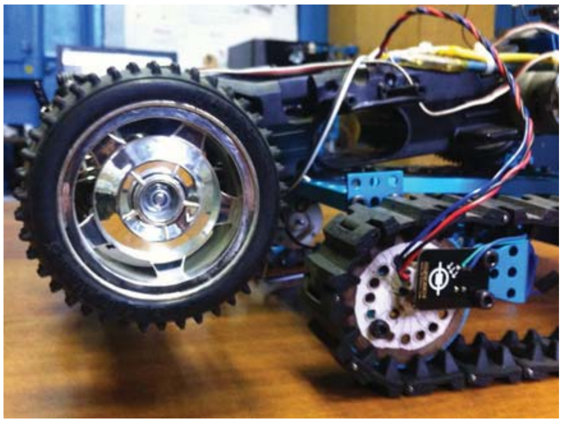

Fig. 5. General view of the experimental model

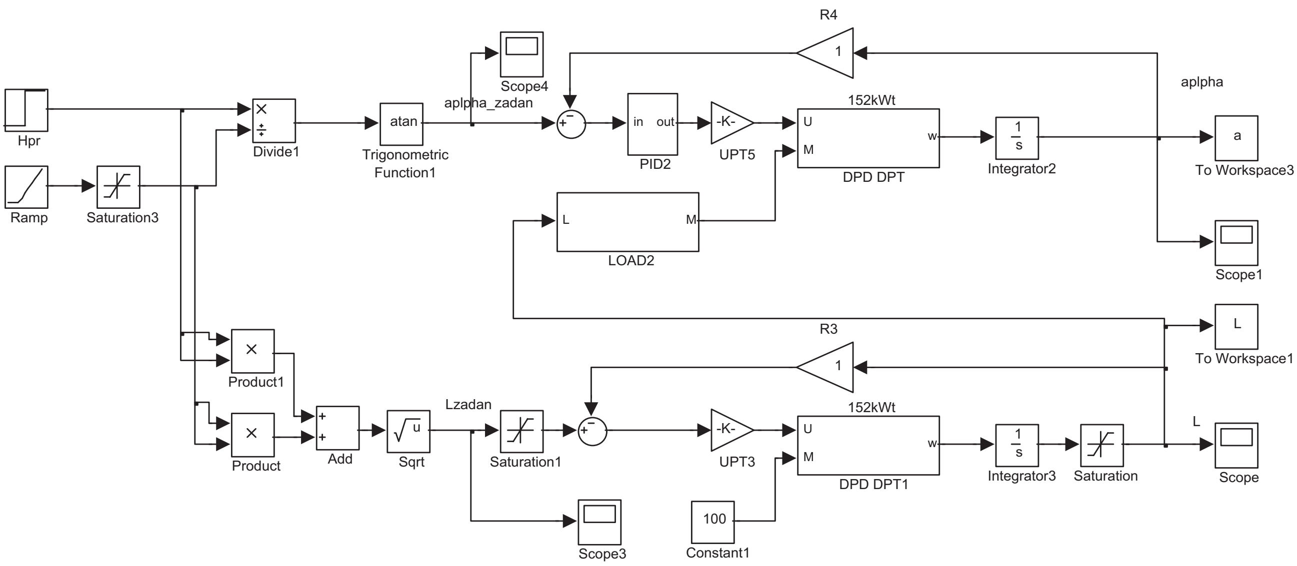

Fig. 6. Simulation scheme of levers extension control. Hpr – obstacle height signal; Ramp – obstacle distance signal; Saturation, Saturation1, Saturation3 – amplitude limiting blocks; Divide1 – divider; Trigonometric Function1 – arctangent calculation block; PID2 – PID controller; DPD DPT – lever angle drive; DPD DPT1 – lever length drive; Integrator2, Integrator3 – integrating blocks; LOAD2 – lever angle drive load; UPT3, UPT5 – gear ratios of DC amplifiers; Product, Product1 – multiplication blocks; Add – summation block; Sqrt – square root calculation block; R3, R4 – transfer coefficients of resistive sensors; Constant1 – load setting on the lever length drive; To Workspace1, To Workspace3 – storing data blocks; Scope, Scope1 – graph displays

A simulation scheme of levers extension control is presented in Fig. 6. The input control parameters to calculate the angle and the length of the levers are a height of the obstacle and a distance to the obstacle (Fig. 7). Based on the calculation scheme, the control signal for specifying the lever length is determined by the formula:

$$L = \sqrt{h^2 + \Delta L^2},$$

where L – a lever length; h – an obstacle height; ΔL – a distance to the obstacle. The following formula is used to calculate a lever inclination angle

$$\alpha = arctg\left(\frac{h}{\Delta L}\right),$$

where α – the lever inclination angle.

Typical simulation blocks are used in the control loop of the lever angle, in particular the standard PID controller. The height of the obstacle is set in the form of a step function while modeling the lever control block. A distance to the obstacle is set by a linear function using the Ramp block that corresponds to obstacle approaching. The distance is limited to a lower limit of zero by using the Saturation3 block, since this value cannot be negative. The angle of the lever inclination is calculated using the Divide1 and Trigonometric Function1 blocks. The lever length is calculated using the Product, Add, and Sqrt blocks.

Saturation blocks are located after the control signal calculation blocks. They limit these signals to the maximum allowed value. For example, the length of the lever cannot be more than 1.5 m, and the angle is limited to 90 °.

A load on the lever length drive is considered constant and is given by a constant. A load on the lever angle drive is defined as the gravitational force of the robot acting on the lever. Transient processes for the system have been studied by means of the *Simulink* program package.

System stability was evaluated by several program methods. The results confirmed its stability, in particular, by the Nyquist criterion (Fig. 8).

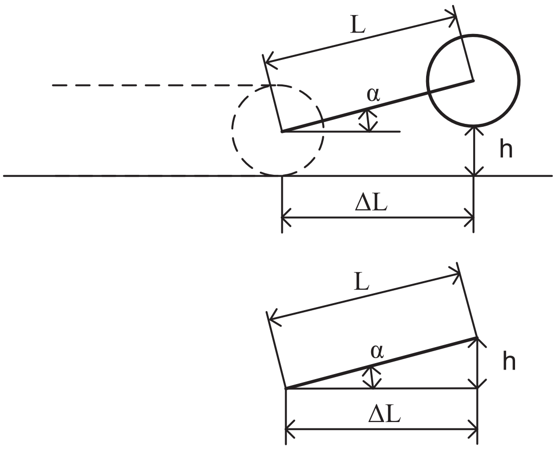

Fig. 7. Levers length and angle calculation L – lever length, h – obstacle height, ΔL – distance to the obstacle, α – angle of the lever inclination

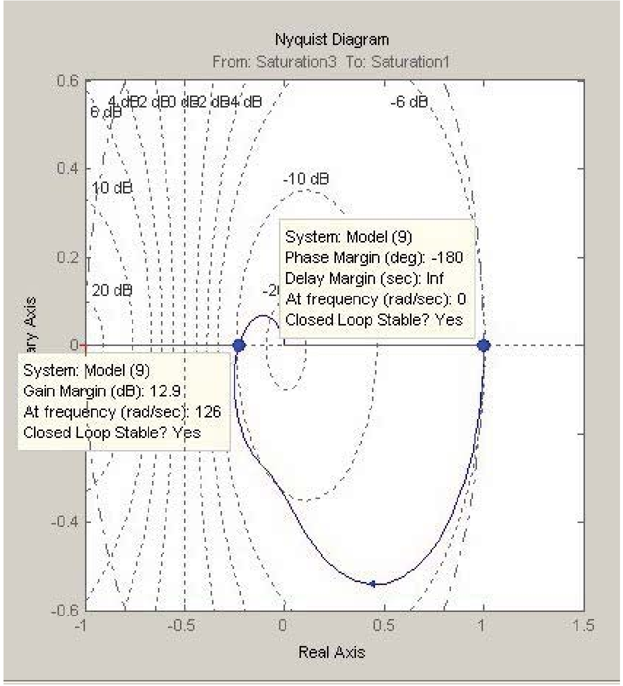

Fig. 8. System stability by the Nyquist criterion

The points marked on the graph correspond to the points of intersection of a frequency response and a phase response of the 0° and 180° lines respectively. As can be seen from the obtained results, the system is stable. Herewith the gain margin is equal to 12.9 Db and the phase margin is - 180°.

VI. CONCLUSION

The new type of autonomous wheel-tracked robots has been developed. It allows automating various works in high-risk areas as well as in places that are difficult for human access.

A kinematic model of the robot has been compiled in the *SolidWorks* environment to study different modes of the robot movement. The automatic control system of the robot is designed to reconfigure the robot structure depending on the kinds of the surface and the obstacle defined by the measuring block of the control system. The designed autonomous robot provides enhanced functionality.

The experimental model with remote control based on standard components has been implemented. Efficiency of the experimental model was tested with a remote control unit over the radio channel. The tests showed that the robot fulfills all motion modes including moving up and down the stairs.

System stability was evaluated by program methods. The *Matlab Simulink* results of the lever drives control simulation confirmed stability of the system with given parameters.

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