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Vertical motion robot in the mining industry

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Abstract. The main directions in the design and programming of vertical motion robots for the mining industry have certain operational risks that underlie the reasons for the lack of consideration of all possible scenarios. The main problem of vertical motion robots is the identification of specific situations. The problem of identification of specific situations occurring during the operation of a vertical motion robot is considered. Some critical situations are proposed for consideration, the forces acting on the robot nodes are illustrated. A model of the robot in MATLAB Simulink environment is created and programmed in order to study the current indicators in the electric motors of the robot. The submodel of the electric motor, based on the data of the technical data sheet of the existing product, which behaves reliably under the conditions of the simulation, is described. The simulation of one of the critical scenarios is considered, and the motor current indicators are analyzed.

1 Introduction

The emergence of vertical mobile robots (VMR) is due to the need to automate various technological operations that require movement or attachment to inclined and vertical surfaces [1, 2].

To date, a large number of prototypes of such robots have been created in the world, in the design of which all the main types of propulsors (wheel, caterpillar, walking) and methods

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of holding (magnetic, vacuum, air screw, mechanical grippers, adhesive materials) are used [3-10].

A common problem of such robots is the need to consider undesirable forces and moments when gripping devices (GDs) engage the supporting surface, which requires the introduction of pliability in the robot actuators [7, 11]. This problem can be solved by estimating the forces and moments in the manipulator links using the currents of the actuating collectorless motors [12-17].

Human work on vertical surfaces and at high altitudes is always associated with a certain risk, so the realization of purposeful actions in extreme conditions with the help of robots instead of people is often a prerequisite for the performance of inspection, painting, washing of building surfaces. Mobile robots can be equipped with mechanical, magnetic, adhesive, pneumatic vacuum gripping devices to ensure movement on exterior building surfaces.

2 Object of study

In the design of the walking robot, it is proposed to use four rotational joints and one linear motion joint. The walking robot we are considering can move on uneven or vertical planes consisting of various flat areas. The robot has a multi-level control system including strategic, tactical and executive levels. The strategic level is designed to solve the tasks of motion planning and data exchange with the control panel. The tactical level is used to transform motion control commands and react to external influences. The executive level is used to control the drive system of the vertical motion robot. In this paper, the features of the executive level of the vertical motion robot are discussed.

The structural scheme of the VMR is shown in Figure 1.

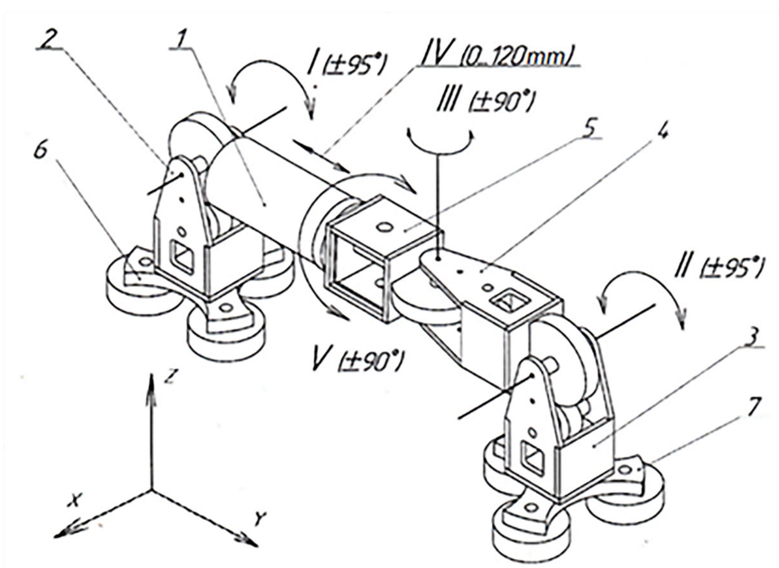


Fig. 1. Design scheme of a walking robot with five degrees of mobility (I-V).

The mechanical system of the robot includes a central link *1* with a telescopic mechanism of translational movement along the *Y* axis (arrow IV), side links *2* and *3* with supports 6 and 7 mounted at their ends. The supports *6* and *7* are connected to gripping devices. On one side, the central link *1* is connected to the side link *2* through a pivoting joint around the X axis (arrow I), on the other side, a pivoting joint *5* around the *Y* axis (arrow V) is attached to the central link. The pivot *5* is connected by a pivot around the *Z* axis (arrow III) to the link *4*, which in turn is connected to the side link *3* through a pivot around the *X* axis (arrow II). The use of the translational movement unit allows changing the distance between the centers of the supports *6* and *7*. Electromagnets are used to hold the robot on vertical surfaces.

The robot is moved as follows. Before starting the movement, both legs *6* and *7* are fixed on a flat surface (vertical, inclined, horizontal). Then one of the supports is unlocked and moved. A set of actuators allows the robot to bend along the longitudinal axis, rotate the gripper, and move the gripper along the axis.

3 Unsecured fixation of the gripping devices on the target plane

In the process of taking a step, an important stage is the fixation of the gripping device to the target surface, as it is the immobility of the gripping devices that ensures the movement of the robot in space. However, during a step, it is impossible to guarantee the fixation of the gripping devices, which is due to the imperfection of mechanisms for ensuring the immobility of the gripping devices and possible defects of the target surface [10].

If the grippers are not securely fixed, stepping can lead to the robot's sole coming off the support, loss of immobility relative to the target surface, and loss of control over the robot with its further destruction. The position of the robot with loose gripping devices is shown in Figure 2.

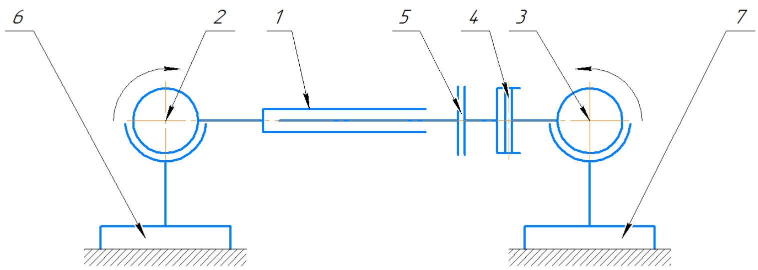
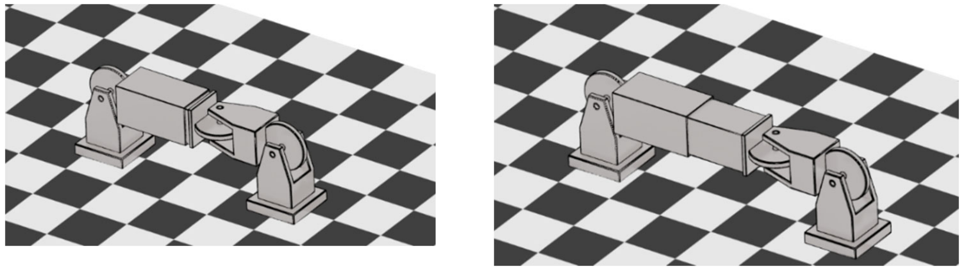


Fig. 2. Position of the robot with the grippers (*7*) loosely clamped in the middle of a step.

This scenario can be prevented by detecting a loose gripper attachment in time, canceling the step, finding a new attachment point, and moving the grippers to the new target position. The fixation check can be performed internally on the vertical motion robot.

To perform the check, the robot performs a telescopic actuator movement in a known closed kinematic situation. The current level in the moving actuator is monitored. Exceeding a critical current level will indicate that the applied displacement force is greater than the clamping reaction force of the grippers. A visualization of the clamping strength test process is shown in Figure 3.



a) b)

Fig. 3. The robot checks that the front gripper is firmly attached. a) Telescopic actuator in initial position; b) Telescopic actuator extended.

4 Securing gripping devices on an unstable surface

While moving over a surface, the robot may encounter an obstacle that is recognized as a possible attachment point for one of the gripping devices, but is in fact pliable when a load is applied. In such a case, when using such an obstacle as a support, it is likely that the obstacle will dislodge and the robot will lose control of its movement, Figure 4.

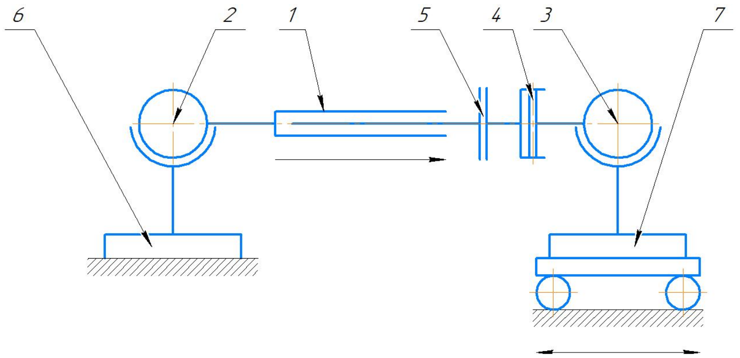
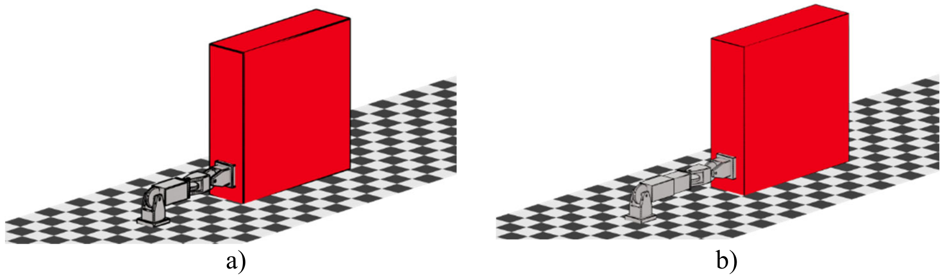


Fig. 4. Securing the gripping device (*7*) on an unstable surface.

In the framework of modeling the following situation is assumed: from the point of view of internal parameters of the robot state (value of current angles of actuators, value of current in electric circuits of electric motors, signals of limit switches) after completion of a step forward, it is impossible to judge about the quality of gripping device fixation without additional check. As such a check, a bending drive movement until the pre-critical current values are reached is suggested.

The expert system for robot state estimation has at its disposal state data and a local motion map containing a set of target local motions for the actuators. The estimation of some external force can be a comparison of the magnitude of this force with the force developed by the robot's actuators for vertical movement. For this purpose, it is necessary to try to make a movement in the direction to be checked, while being in a known position of the closed kinematic scheme.

In this case, the obstacle stability test consists of trying to move the obstacle. The telescopic actuator extends to move the obstacle and the current level is also monitored. If displacement occurs, but the current level does not exceed critical values, then a decision can be made as to the strength of the obstacle being tested. Figure 5 shows the initial stage of testing an unstable obstacle, with the robot attaching the gripper to the target surface.



a) b)

Fig. 5. Visualization of the inspection of a shearable obstacle by applying force to the telescopic actuator of a vertical displacement robot. a) Telescopic actuator is folded; b) Telescopic actuator is extended, the obstacle is moved.

5 Conclusions

The value of the current level signal in the case of a firmly clamped gripper shows an increase in resistance at the start of movement. This is due to the increasing reaction force of the gripper support, which is influenced by the telescopic actuator. The fluctuation of the current signal levels in the motor circuit at the beginning and end of the movement is due to the correction applied.

The shear check of a solid obstacle induces a support reaction force, which is reflected in an increase of the current signal level in the motor circuit. At the same time, the current level in the case of the shear obstacle is higher than in the case of the gripper slipping because the displaced weight of the robot body and the gripper is less than the combined weight of the robot body, the gripper and the shear obstacle. The same pattern can be seen in the difference of current levels when the robot gripper slips and when the gripper slips with the shearable obstacle.

The obtained results allow us to proceed to the development of algorithms of functioning of the tactical and executive levels of the VMR control and further testing of the obtained algorithms of the control system of the vertical displacement robot drives.

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