On the movement of the rope robot on a vertical surface

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Abstract A method of moving a cable robot on a vertical surface with support on it is considered. The motion of the robot with adjustable, with the help of the load, the position of the center of mass is investigated. The stages of overcoming obstacles by such a robot and the equations of motion at individual stages of movement are described.

1. Introduction
Moving robots on vertical surfaces allows you to solve various applied problems in the field of construction, monitoring, cleaning, technical maintenance. Their use is justified in conditions dangerous to human life, in hard-to-reach places, as well as during labor-intensive work. The range of tasks is expanding with the development of technology and methods of movement.

Robots capable of moving on vertical surfaces are used for cleaning Windows [1], monitoring the condition of the surfaces of technological structures [2], aircraft [3, 4], ships [5]. Most types of vertical movement robots use vacuum suction cups to hold and move on the surface [6,7], which are sometimes equipped with a crawler mechanism to move them, create a pressure vacuum under them, use magnetic force [8], use Bio-Inspired Adhesion [9-11], and use cable or rail supports [10,11]. At the same time, cable robots are actively studied [12-14], the construction of which have a number of advantages, in particular they are more reliably held in a given position due to the use of geometric indestructible bonds.

It is known a mathematical model of robots moving on vertical surfaces with the use of cable thrusters and support on the surface itself [15]. The method of movement of such a robot is similar to the method of movement of climbers, who are also held on the rope with their feet resting on a steep wall, and move when moving their feet and adjusting the length of the rope.

2. Problem Statement
The task is to develop an algorithm for overcoming obstacles (ledges and crevices) on a vertical surface by robots with cable thrusters.

3. Method of overcoming obstacles
The main elements of the robot (body, cables, supports) can have different constructions. Thus, the robot supports can be made in the form of wheels, tracks, walking movers, etc. (figure. 1). The main problem of such robots is reliable interaction with the supporting vertical surface, overcoming irregularities on it and the necessary maneuverability.
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Figure 1. Rope robot support options: 1-hull, 2-cable, 3-track, 4-stepper motor, 5-stepper motor

To overcome obstacles, such robots either turn relative to any support (wheeled and tracked), or tear off the support to carry them over the obstacle (walking robots). In both cases, the reaction of the supports and the moments of forces acting on the robot body, the friction forces in the supports change. The range of variation of these forces is narrow, and excessive rotation of the robot body may tip it over, that is, loss of stability. For a more reliable hold on the surface, it is proposed to use an adjustable weight mounted on the robot body (figure 2a). The number of cables and supports is unlimited, but with forward motion, the use of one cable and two supports is sufficient to consider the proposed scheme of movement. The design scheme of such a robot is shown in Fig 2B. the Translational motion of the robot is described by a system of equations (1) taking into account the inequalities (2).

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\begin{align*}
N_1 + N_2 \cdot T \cdot \sin \alpha &= 0 \\
F_1 + F_2 + T \cdot \cos \alpha - G - P &= 0 \\
N_1 \cdot a_1 \cdot N_2 \cdot a_2 \cdot \left( F_1 + F_2 \right) \cdot H \cdot \sin \alpha + G \cdot b - P \cdot l + M_{f k 1} + M_{f k 2} &= 0 \\
F_1 &\leq f \cdot N_1; F_2 \leq f \cdot N_2; N_1 \geq 0; N_2 \geq 0
\end{align*}
\]

Changing the distance \( l \) to the load, allows for the implementation of inequalities (2) in a wide range. This allows you to increase the stability of the robot, when it works in the open space when exposed to it, for example, wind load, or load from actuators that can be installed on the robot.
The design of the robot the supports of which are free wheels equipped with a braking mechanism is considered. The system of governance (1) and inequality (2) are also valid for him. It is possible to allocate following stages of overcoming obstacles by robot of this type: moving on two supports or the approach to the obstacle (figure 3a), rotation around one support (figure 3b), the movement on one support (figure 3c), lowering on all supports (figure 3d), in this case there are options when the support will be located on the obstacle or behind, it rotating around the support behind the obstacle (figure 3e), the movement on one support (figure 3f) lowering to the support and return to the starting position (figure 3g).

Figure 2. Scheme of cable robot with adjustable load a)kinematic scheme, b)calculation scheme 1-body, 2-rope, 3-support, 4 adjustable weight, 5-vertical surface, l-adjustable size

Figure 3. Diagram of the stages of overcoming obstacles by the robot, 1-vertical surface, 2-obstacle, 3-hull, 4-rope, 5-wheel with brake, 6-controlled load.
In the first stage, the robot makes a forward movement on the surface by changing the length of the cable and approaches the obstacle. The wheels of the robot are thus disinhibited, and the adjustable load is located in such a way that the sum of the moments from all the forces acting on the robot is zero. In the second stage, when the robot is close to the obstacle, the load moves to turn the robot, creating an additional moment of force. At a certain point, the upper of the robot supports comes off the surface, and to prevent the robot from tipping over, the wheel of the lower support is braked. The friction force created by this wheel balances the system. When the robot reaches the desired position, the movement of the adjustable load stops. Then the movement of the robot begins on one support, at the same time, second one is the same time is transferred over the obstacle. The movement is due to the reduction of the length of the cable and the release of the wheel of the lower support, so that the additional moment of friction in the wheel compensates for the rolling resistance force. At this stage, with a small change in the angle of inclination of the cable, the position of the control load does not change. When overcoming the obstacle carried by the support, the adjustable load is returned and as a result the robot returns to its original position. The following stages of overcoming the obstacle are performed according to a similar scheme.

The first phase (moving on two supports) the robot's motion is described by equations (1) and corresponds to the calculation scheme shown in figure 2b. The motions at the remaining stages are described by similar systems of equations. The solution of equations (1) allows you to determine the necessary parameters to control the movement of the robot, at the first stage of movement. The second stage of moving the robot (turning around one support) is illustrated by the design diagram figure 4 and describe the equations (3). Using these equations, you can determine, for example, according to (4) distance to the regulated goods from the angle $\beta$ of inclination of the robot relative to the vertical surface as well as to identify other laws between the characteristic parameters of the robot. The use of the obtained regularities allows to predict the behavior of the robot when moving, and as a consequence allows to create a control system of the robot capable of maintaining a stable position of the robot at all stages of its movement.

\[
\begin{align*}
N - T \cdot \sin \alpha &= 0 \\
F - G - P + T \cdot \cos \alpha &= 0 \\
- G \cdot a \cdot \cos \beta + T \cdot H \cdot \sin \alpha - P \cdot c \cdot \cos \beta &= 0
\end{align*}
\]
4. Conclusion

Despite the considerable variety of ways to keep the robot on a vertical surface, the use of indestructible bonds (cables) is the most reliable way. The described method of movement of the robot allows it to move on a vertical surface, to overcome obstacles on it, and also to resist to influence of external forces. Thus, the study of control methods of such robots is an urgent task.

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References

[1] Elkmann N, Felsch T, Sack M, Saenz J, Hortig J Innovative service robot systems for facade cleaning of difficult-to-access areas. In Proceedings of the 2002 IEEE/RSJ International Conference on Intelligent Robots and Systems Lausanne Switzerland 30 September–4 October 2002 Volume I pp 756–762.
[2] S. Park, H D Jeong and Z S Lim Design of a mobile robot system for automatic integrity evaluation of large size reservoirs and pipelines in industrial fields in Proc. of the IEEE/RSJ IROS Las Vegas Nevada USA October 2003 pp 2618–2623.
[3] P G Backes, Y Bar-Cohen and B Joffe, The multifunctional automated crawling system (macs) in Proc. of the IEEE ICRA Albu- querque New Mexico USA April 1997 pp 335–340.
[4] H Chen, W Sheng, N Xi and J Tan Motion control of a micro biped robot for nondestructive structure inspection in Proc. of the IEEE ICRA Barcelona Spain April 2005 pp 480–485.
[5] S Hirose, A Nagakubo and R Toyama Machine that can walk and climb on floors, walls and ceilings in Proc. of the Fifth ICAR Pisa Italy June 19–22 1991 pp 753–758.
[6] Gradetskiy V G, Veshnikov V B, Kalinichenko S V, Kravchuk L N Upravlyayemoye dvizheniye mobilnykh robotov po proizvolno oriyentirovannym v prostranstve poverkhnostiam. M. Nauka 2001 369 p (in Russian).
[7] W Brockmann Concept for energy-autarkic, autonomous climbing robots in Climbing and Walking Robots, M O Tokhi, G S Virk and M A Hossain Eds. Springer February 2006 pp 107–114.
[8] Robot s magnitno-lentochnym printsipom vertikalnogo peremeshcheniya Bykov N V, Vlasova N S, Gubanov M Yu Ekstremalnaya robototekhnika: Trudy mezhdunarodnoy nauchno-tekhnicheskoy konferentsii Sankt-Peterburg: Izdatelsko-poligraficheskiy kompleks “Gangut” 2019 – P 122 – 123 (in Russian).
[9] A T Asbeck, S Kim, A McClung, A Parness and M R Cutkosky Climbing walls with microspines in Proc. of the IEEE ICRA Orlando Florida USA May 2006 pp 4315–4317.
[10] Nansai S, Mohan R E, A Survey of Wall Climbing Robots Recent Advances and Challenges Robotics 2016 5 P 14.
[11] Silva M, Machado J, Tar J A survey of technologies for climbing robots adhesion to surfaces Proc. of the 6th IEEE Conference on Computational Cybernetics November 27-29 2008 Stara Lesna Slovakia P 127—132.
[12] Bosscher P (2004). Disturbance robustness measures and wrench-feasible workspace generation techniques for cable-driven robots. PhD thesis Georgia Georgia Institute of Technology.
[13] Bruckmann T, Mikelsons L, Brandt T, Hiller M and Schramm D Wire robots Part I – Kinematics, analysis and design In Parallel Manipulators. Vienna I-Tech Education and Publishing.
[14] Maloletov A V, Uchet konstruktisiy napravlyayushchikh rolikov i mehanizmov namotki pri upravlenii dvizheniyem trosovogo robota A V Maloletov, A S Klimchik, K V Kostenko Izvestiya VolgGTU Seriya Aktualnyye problemy upravleniya. vychislitelnoy tekhniki i infor-
[15] Sharonov N G, Efimov M I, O pereshchenii po vertikal'noy sherokhovatoy poverkhnosti s pomoshch'yu trosovykh dvizhiteley Izvestiya VolgGTU nauchnyy zhurnal № 3 (226)/VolgGTU Volgograd 2019 p 51-54 (in Russian).