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PARAMETRIC SYNTHESIS OF A MOBILE ROBOT FOR SERVICING PARK TREES

Abstract: The article deals with the problem of creating mobile robots for servicing park and forest woodlands. An analysis of modern designs of robotic devices for tree trimming and a description of a fundamentally new design of a mobile robot of arbitrary orientation on tree trunks are given. The article describes a completely new design of a mobile robot for pruning bacterial damage to trees. Application of the proposed mobile robot allows maintenance of trees regardless of their topology and breed. An improved methodology for the parametric synthesis of the technical parameters of the robot is described. The difference in the proposed methodology for optimizing the design and technological parameters of a mobile robot is that the robot is presented in the form of a multi-level technical system in which target functions and independent factors are interconnected at different levels of the hierarchical system.

Keywords: mobile robots, stepping mechanisms, climber robot, tree trimming

Relevance of research. The use of vehicles in the form of various models of tractor equipment for servicing parks and woodlands has a negative impact on the environment, since these vehicles have an inherent emission of pollutants due to the use of drives with internal combustion engines.

An alternative to the use of motor vehicles for this purpose is the creation and operation of mobile robots of arbitrary orientation, known in the international publications under the term Climber Robot. This new modification of mobile robots is equipped with the means of holding the robot on the surface of an arbitrary orientation relative to the horizon of the technological space. Considering that this type of robotics fully meets the requirements of environmental cleanliness, the following studies should be considered relevant.

Analysis of recent research and publications. The lack of mobility of known machines for contour pruning fruit or park trees, which usually include a frame mounted on the chassis with a cutting device mounted on it in the form of saw blades or vertical knives, can be compensated by the use of mobile robots of vertical movement [1, p. 36] or, the so-called Climbing Robots. These works include both wheel and stepper gearboxes, and most importantly, they are equipped with a means to grip the robot's surface with vacuum or mechanical devices, as well as a remote control system. However, the absence of these robots, any technological equipment for pruning trees does not allow them to be used for this purpose. Also of interest is the robot [2, p. 7] for monitoring tree and shrub stands. This robot creates virtual 3D images of tree crowns to identify pruning objects. However, in the design of this robot, as well as in the known combines for pruning trees, uses a self-propelled chassis, deprived of the ability to move directly on the tree, which limits its technological capabilities.

Unlike the previous technical solution, the six-legged robot [3, p. 5−7] has the ability to move directly through a tree trunk. When equipped with this robot with a suitable technological tool, it can be used for pruning tree branches. However, the lack of design of the device of rotation does not allow the robot to change the trajectory of movement, which significantly limits its manoeuvrability as a mobile vehicle for moving trees. The mobile robot described in the monograph [4, p. 37−39] contains housing with grips made in the form of claws, forming the phalanx of the grip and supplied with springs to engage the grip with the tree trunk and a linear actuator to open the grip. However, when performing technological operations such as pruning tree branches, it is necessary to increase the force of the springs (or rather their rigidity), which compress the claws of the grips, and, consequently, increase the power of the linear actuator to open the claws of the grips, which inevitably leads to an increase in the weight of the device and hence the increasing gravitational load on the robot. The analysis of the given technical solutions indicates the necessity of increasing the reliability of mobile robot operation on the trunk or tree branches. Thus, the task of creating a mobile robot for servicing woodlands remains relevant.

The design of the robot. The fundamental novelty of constructive solutions of mobile robot is confirmed by the qualification expertise of the State Enterprise "Ukrainian Institute of Intellectual Property" [5, p. 3]. A dynamic model of a similar robot was developed in [6, p. 34]. In Fig. 1 shows a fundamentally new design of a mobile robot.

The proposed design of a mobile robot for tree maintenance can significantly improve the reliability of operation by applying self-locking mechanisms in the design of gripping the robot to grip it with the surface of the tree, and the possibility of arbitrary orientation is provided by dividing the housing of the robot into two parallel platforms, supplied by the actuator of relative rotation. The mobile robot works as follows. In the initial position, the grips *A* and *D* (Fig. 1) of robot 1 are engaged with the tree trunk, and the grips *B* and *C* are free from grip. According to the commands of the remote control include engines 2 and mounted on their shafts gears 3 reports the movement of the housing 1 robot in the direction of *Z*. As a result, the platforms 4 and 5 make the movement ± ΔZ in the *Z* axis in the coordinate system XYZ relative to the tree trunk.

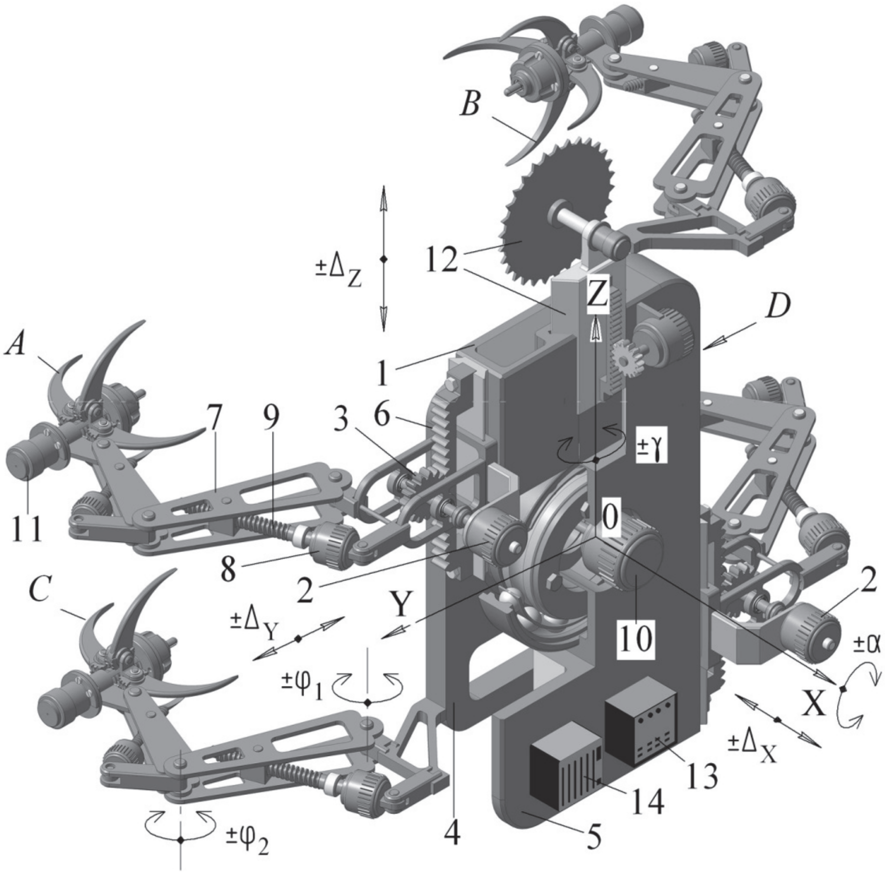

Figure 1. Mobile robot for pruning trees

To perform the next step of the robot, the grips *B* and *C* are engaged with the tree trunk, and the grips *A* and *D* are released from the clutch. When the engines 2 are reversed, their gears 3 are rolled up on the rack 6. The housing of the robot 1 is now fixed to the tree trunks through the grips *B*, *C*. Clamps A and D free from grip move by the same value ± ΔZ. To continue translational motion, the stated cycle is repeated with the clutch paired diagonally located grips *A*, *D* and *B*, C, as well as with the corresponding reversing of the engines 2. Simultaneously with the translational movement of the work along the tree, depending on the topology of its trunk, make angular movement of the pedipulators. This includes motors 8 which rotate the self-locking screws 9 at a speed ω1 through the hinged nuts, tell the pedipulators 7 angular motion ± φ1 according to a given program or at the command of the operator. Likewise, angular motions ± φ2 and pedipulators of other legs do the job, equipped

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with the same self-locking screw drives with speed ω2, but with less power. The program of combinatory of movements is determined by the tree topology.

The motion of rotation of the mobile robot, more precisely its platforms 4 and 5, is carried out in alternate grip of grips *A*, *D* and *B*, *C*. For example, when the tree trunk is engaged grips A and D, and the grips *B* and *C* are free from grip, then when turning the engine 10 through the transmission rotates the lower platform 4 around the axis X by an angle $\pm\ \alpha$. And when the clamps B and C are engaged in the lower platform and released from the clutch with the tree trunk of the clamps *A* and *D*, when the motor 10 reverses, the upper platform 5 returns to the angle $\beta = \alpha$. The mobile robot has five degrees of freedom, namely: translational motion $\pm\ \Delta z$ along the *Z* axis under the action of the actuators and rotation $\pm\ \alpha$ around the X axis during the rotation of the actuator 10. And, as a result of angular motions $\pm\ \varphi 1$ and $\pm\ \varphi 2$, two translational motions $\pm\ \Delta x$, $\pm\ \Delta y$, and angular motion $\pm\ \gamma$ around the Z axis. These five degrees of mobility are quite sufficient for an arbitrary orientation of the robot when performing tree trimming of any topology.

Actually erection and dilution of grips *A*, *D* and *B*, *C* is done by means of the respective motors 11 through a worm gear. This worm gearbox provides reliable hold on the barrel in the event of shutdown or deactivation of the autonomous power supplies of the drive. Cutting of branches of trees, knots and various growths on tree trunks is carried out by technological module 12, consisting of a circular saw and an electromechanical drive. The robot is controlled by the on-board computer 13 and powered by a battery pack of 14.

In Fig. 2 shows the various provisions of the mobile robot on the tree with the growth to be removed. In the XYZ coordinate system, the robot moves along the tree trunk following the commands of the remote control system in the Z-axis direction (Fig. 2,a), having travelled the distance ΔZ to the bacterial damage of the tree, the robot is stopped.

The command eliminates the grips of the grips of the upper platform 1 and rotates it in the direction of growth on the angle $\beta = \alpha$ (Fig. 2,b) to coincide with the lower platform. Then, using a disc cutter cut off the growth, carrying out the appropriate motion control robot in the manner described above. The proposed mobile robot can be implemented in the conditions of industrial production using standard equipment, modern materials and technologies at any engineering enterprise.

a b

Figure 2. The position of the mobile robot on the tree with bacterial growth

Parametric synthesis of the robot. Dynamic analysis of a mobile robot of an arbitrary orientation in the technological space was performed in [6], in which a mathematical model of the dynamic load of a robot and the results of simulation modelling with the reflection of graph analytic dependences of structural and technological parameters of a robot are presented.

Parametric synthesis of a mobile robot will be performed on the basis of a separately selected morphological structure [7]. According to the terms of reference, it is necessary to develop a design of a mobile robot for servicing park woodlands, in particular for trimming growths, twigs and branches on trees. Based on the method of morphological construction, the synthesis of the necessary structure, which is highlighted on the morphological graph (Fig. 3), with the dashed lines with arrows and the designations of morphological characters A, B, C and D, of combinations reflecting: wood arrays → technological operations → electric drive with walking gear → and mechanical grips for clutching the tree trunk. The structure of the mobile robot is shown by displaying the target functions to optimize its parameters.

According to the technical specification, the mobile robot 1 (Fig. 3, a), equipped with a step-by-step transmission 2 with electric actuators 3 (C) and mechanical (D) grips 4, must move along the tree trunk 5 in the XYZ coordinate system by the value ΔZ and perform technological operation (A), which is to cut a tree bush with a disc milling cutter 7. Then, according to the structure selected from the morphological graph in Fig. 3 (b), the following parameters are subject to optimization: modes of technological operation (cutting of growths) → characteristics of electric drive → stepping transmission → design parameters of mechanical grip.

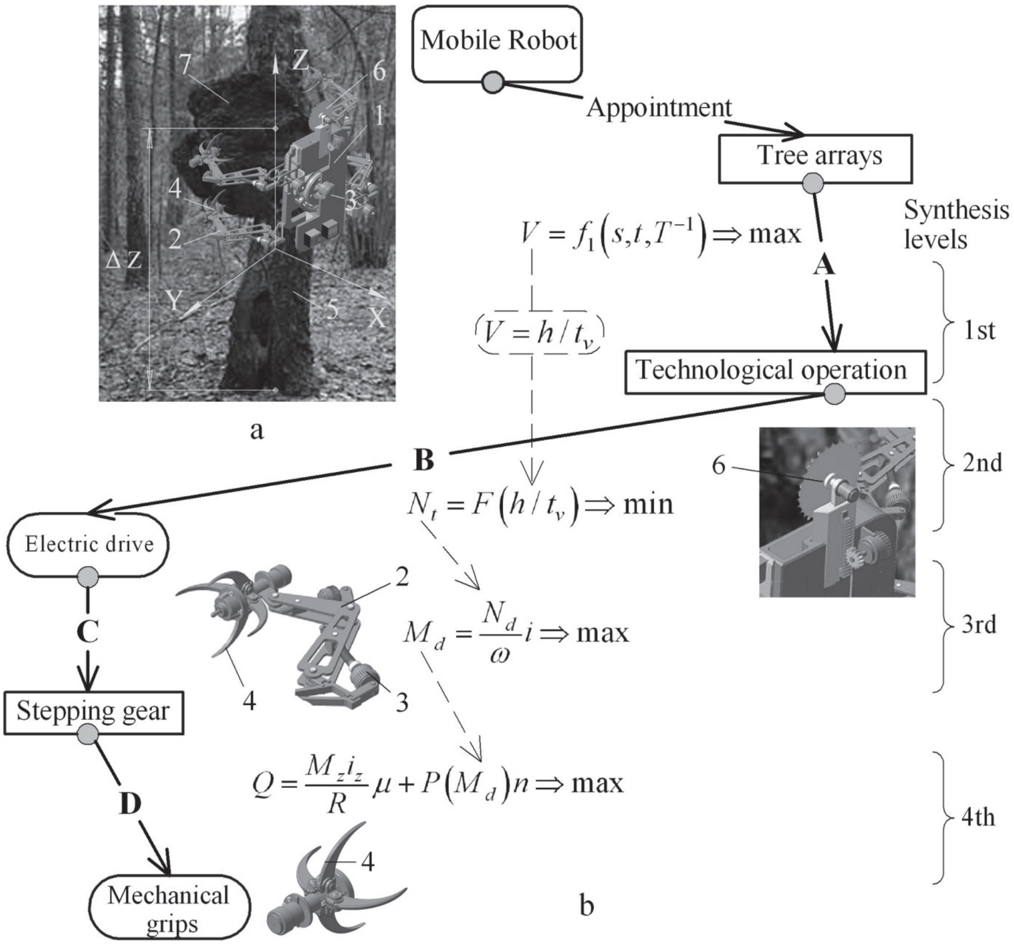

Figure 3. Structural-parametric model of a mobile robot for pruning trees

Next, we outline the proposed modification of the parametric synthesis technique for such a multi-level hierarchical structure as a mobile robot. The proposed modification is to reflect not only the existence of a link between the optimization criteria and the independent variables within the target functions, which is already known (ie trivial), but also the relationship of the target functions themselves at different levels of the technical system (see dotted arrows in Fig. 3, b), in this case, the structure of the mobile robot.

At the 1st level of parametric synthesis for morphological combination "A", the objective function, including the modes of technological operation, can be represented in general form as a function of the speed of cutting wood by a disk cutter:

$$V = f_1\left(s, t, T^{-1}\right) \Rightarrow \max, \tag{1}$$

with restrictions: $s = f_{11}\left(\sigma\right)$; $t_1 \le t_i \le t_n$, where: s – of the feed on the tooth of the milling cutter; σ - limit of strength of wood of a certain breed; t – is the depth of cut within the range of values *t1… tn*; T – is the tool life of the tool.

At the 2nd level of synthesis for the morphological combination of traits "B" (technological function - drive), the target function can be written as a function of the power of performing the technological operation (in this case, cutting):

$$N_t = F\left(h / t_v\right) \Rightarrow \min, \tag{2}$$

where: F – the effort of cutting wood; h is the thickness or diameter of the cutting object (branches, bitch, growth); t_v – cutting time; because $\left(h / t_v\right) = V$, it can be written as $N_t = FV \Rightarrow \min$, thus reflecting the *relationship* of the 1st and 2nd levels of synthesis.

For level 3 synthesis of the morphological combination of traits "C" (drive - transmission), the objective function can be represented as the torque *M*d of the drive:

$$M_d = \frac{N_d}{\omega} i \Rightarrow \max; \quad N_d = M_d \omega \geq N_t, \tag{3}$$

where: *Nd* i ω – engine power and angular velocity; i – is the gear ratio of the amplifier-gear unit (i.e. gearbox).

At the 4th level of parametric synthesis for the combination "D" (the actuator – the system of coupling with the surface of the moving robot), the desired function is also desirable to associate with the previous functional. This can be done by writing in the form of a target expression function for the force of adhesion Q of mechanical grip with the surface of movement of the mobile robot:

$$Q = \frac{M_z i_z}{R} \mu + P\left(M_d\right) n \Rightarrow \max; \quad Q \geq \left(F + mg\right) K, \tag{4}$$

where: *M*z and *i*z are the torque and gear ratio of the gripper; R – capture (length) of the capture claws; μ – is the sliding friction coefficient between the material of the gripping claws and the surface of the tree; P – is the effort of one leg from the number “*n”* of the stepping gear units as a function of the torque of the engine *M*d in expression (3); m is the mass of the robot; g – acceleration of free fall; K is the reserve factor (1,2… 1,5) to compensate for inertial transients.

The stated target functions of parametric synthesis are simplified and are by no means exhaustive; they can be supplemented and modified, especially when a similar optimization problem is posed for other branches of the morphological graph. At this stage, according to the method of parametric synthesis, it is extremely important for the parametric relationship of the objective functions to optimize the components of the structure, as a hierarchical multilevel technical system, shown in the example of a mobile robot, in particular, for pruning trees. Creating such formalized models, i.e. in the interrelation of target functions at different levels of the hierarchy of the system, will maximize their adequacy to the real conditions of use of mobile robots. Actually, the methods of solving the problem of finding local extremes of optimization criteria at each of the levels are quite well known and may include both analytical and numerical methods. In any case, finding quasi-optimal solutions, of course, contributes to the improvement of design efficiency, and therefore the operation of mobile robots of arbitrary orientation in the technological space, as a new type of means of production.

Conclusion

Thanks to the performance of the work in the form of two parallel platforms, supplied by the actuator of rotation relative to each other, the robot has virtually no restrictions on the angle of rotation, which ensures its sufficient maneuverability when moving through the trees of any topology and breed.

The gearing of the actuator-lever claws for clutching the robot with the surface of the movement by self-locking worm gearing eliminates the opening of the grips in case of actuation of the actuators, and therefore provides a guaranteed retention of the robot on the tree, that is, increases its reliability of operation.

Modification of parametric synthesis, which consists in the interrelation of target functions at different levels of synthesis, makes it possible, by finding quasi-optimal solutions, to significantly improve the design efficiency of mobile robots, and, consequently, their future operation.

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