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# Manipulator-tripod on mounted parallelogram mechanism

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**Abstract.** The objects of development were a universal loader mounted on the base of the manipulator-tripod, the algorithm and method of the "copy" control, which allows to ensure the movement of cargoes along a predetermined path.

## 1. Introduction

In the modern world mobile robots have many various applications and their main working part is a manipulator. Robotic handling systems are used for loading and unloading, transport and storage operations in various technological processes [1, 2].

Manipulators equipped with actuators of positional tracking links and controlled by the human operator, allow you to mechanize a variety of labour-intensive loading and unloading operations. But even when working with the same type of cargoes, the operations vary from cycle to cycle, which is caused by a change in the coordinates of the initial and final points of the trajectory, i.e. the working operation is not completely clear in advance but varies widely [3, 4].

Such problems can be solved by improving and developing manipulators, which have ample opportunities for mechanization of various technological processes [5, 6, 7]. In such requirements it is possible to use the loading manipulators, in the kinematic chains of which there are spatial executive mechanisms that allow the movement of the cargo gripping arm along complex trajectories, and with a relatively simple design [8].

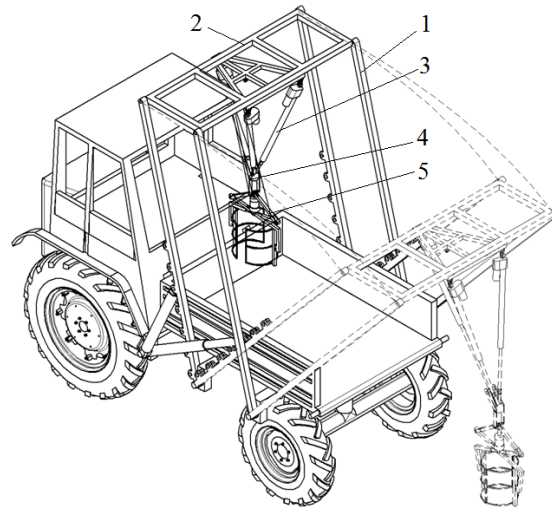
## 2. The design of the loader

To achieve the above goals a universal parallelogram platform with the attached manipulator-tripod was developed, as well as a control system for this mechanism.

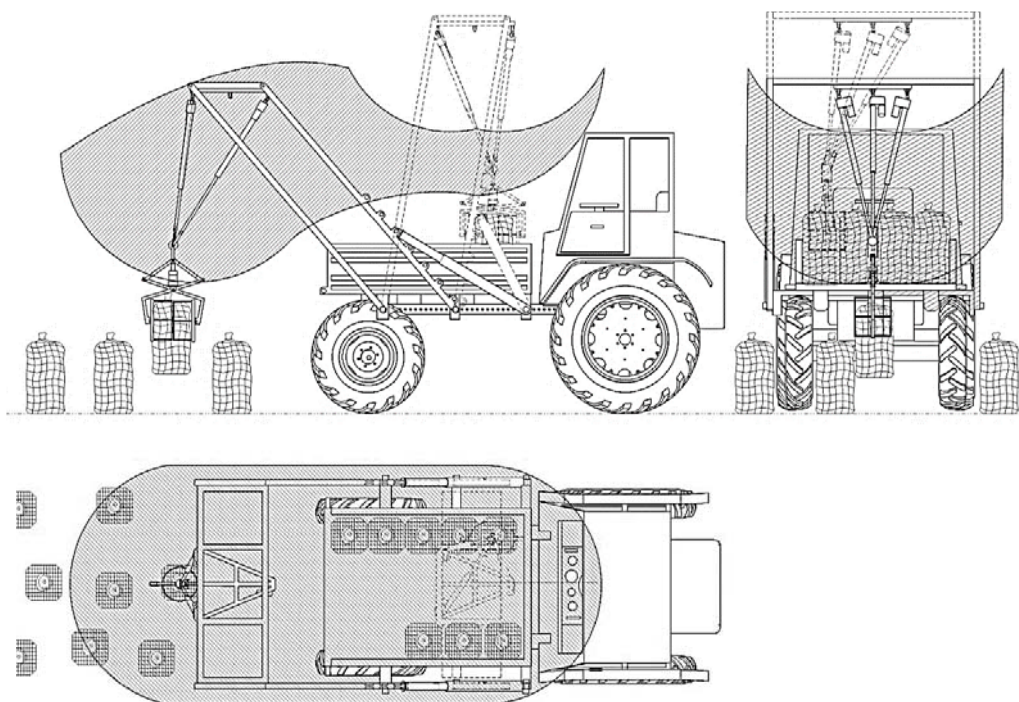
The design of the loader is hinged and it is mounted on the spars of the self-propelled chassis (Fig.1).

The role of the loader boom is performed by the spatial parallel-program mechanism 1, which ensures the horizontal position of the platform 2 at different angles of rotation of the boom. On the platform 2 is fixed manipulator-tripod 3, equipped with a universal joint 4, with which the cargo's gripper 5 is attached. The manipulator-tripod provides movement of the cargo gripping device on width of a body of the self-propelled chassis.





**Figure 1.** Mobile robot loader with cargo's gripper device based on T-16M self-propelled chassis.



**Figure 2** Service area for gripping nets of the robot-loader.

The geometric parameters of the mechanism are justified in such a way as to ensure the width of the load more than the width of the body of the self-propelled chassis (figure 2).

The calculations showed that each drive electric cylinder of the parallelogram mechanism should provide a force of  $P_{\text{count}}=3.28$  kN. Thus, at operating speeds of electric cylinder rods up to  $V_{\text{stock}}=0.25$  m·s<sup>-1</sup> the required power of the actuator motor is  $N_{\text{needful}}=0.82$  kW.

### 3. Control system

Manipulators of parallel structure along with the advantages have a significant drawback – the difficulty of manual control. This drawback is due to the need for simultaneous control of multiple drives. It is impossible to set the movement on a given trajectory, by partial movements of each degree of mobility of such manipulators, also, manual control of several degrees of mobility of the loading manipulator leads to rapid fatigue of the operator.

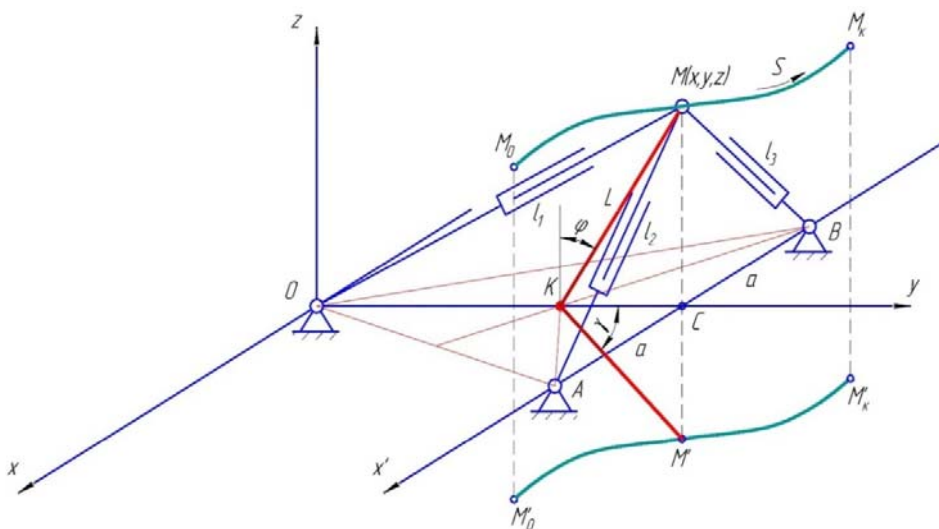
From the analysis of control systems it was revealed that the well-known and intuitive principle of manipulator's control with the participation of the operator is copying [9].

Control of the loading manipulator-tripod is a complex task, including planning and synthesis of trajectories, solving the problem of positioning the cargo at the initial and final trajectory points, setting and implementing the law of movement of the cargo along the trajectory [10, 11].

The algorithm of control of the gripping arm (p. M) of a manipulator-tripod is built basing on the conditions for the optimal trajectory tracking  $M_0M_k$  (figure 3). The condition of optimal tracking of the trajectory of the point M assumes that the movement of the drive mechanisms of the control system and the rods of the working cylinders are connected by relations:

$$\begin{aligned} S_{M_M} &= S_{M_p} \cdot \lambda^{-1}; \\ V_{M_M} &= V_{M_p} \cdot \lambda^{-1}. \end{aligned} \quad (1)$$

where  $S_{M_M}$ ,  $V_{M_M}$  – displacement and velocity of point M of the manipulator;  $S_{M_p}$ ,  $V_{M_p}$  – the corresponding displacement and velocity of point M of the handle of the control system,  $\lambda$  – the scale coefficient.



**Figure 3.** Calculation scheme for the formation of the control algorithm.

Let us suppose, the manipulator is characterized by the following geometric dimensions:  $OM=\lambda l_1$ ;  $AM=\lambda l_2$ ;  $BM=\lambda l_3$ ;  $OC=c$ ;  $OK=d$ ;  $OA, AB, OB$ ;  $OA=OB$ ;  $AC=CB=a$ ;  $MK=L$ .

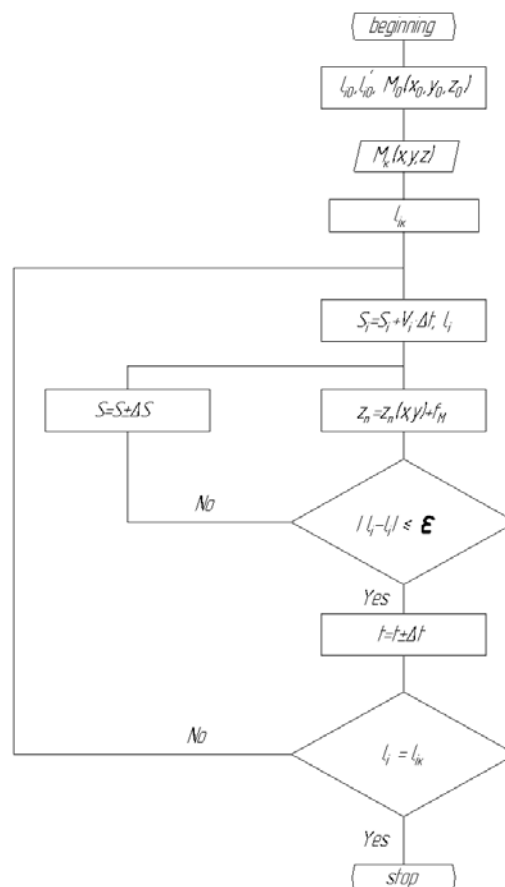
The position of the point M can be described as equations of relations:

$$\begin{aligned} l_1^2 &= x_M^2 + y_M^2 + z_M^2, \\ l_2^2 &= (x_M + a)^2 + (y_M + c)^2 + z_M^2, \\ l_3^2 &= (x_M - a)^2 + (y_M + c)^2 + z_M^2, \\ L^2 &= x_M^2 + (y_M + d)^2 + z_M^2. \end{aligned} \quad (2)$$

The reproduced curve is represented as the function  $f_M = f(x_M, y_M)$ , the initial position of the point  $M_0$  of the driving mechanism is  $\lambda x_0, \lambda y_0, \lambda z_0$ , (i.e.  $M_0(x_0, y_0, z_0)$ ), besides the point  $M_0$  coincides with one of the points of the trajectory of the reproduced curve and corresponds to the angles of the link  $L - \varphi_0$  and  $\gamma_0$ .

Let us mark the starting lengths of the links of the master as  $l_{10}, l_{20}, l_{30}$ , and the courses of the rods, respectively,  $S_1, S_2$  and  $S_3$ .

The algorithm of formation of the control program for electric cylinders of the manipulator is presented in figure 4.



**Figure 4.** The algorithm of formation of the control program for electric cylinders of the manipulator.

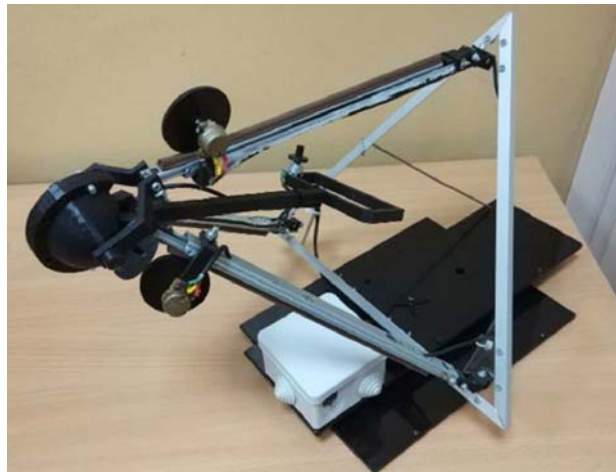
The current readings of the position of sensors of the actuator rods  $l_{i0}$  and the positions of the rods of the control mechanism  $l'_{i0}$  are read in the body of the algorithm. According to the readings from equations (2) are Cartesian coordinates of the starting point of the tong position  $M_0(x_0, y_0, z_0)$ . Further, set the coordinates of the end point of positioning of the load  $M_k(x, y, z)$  and the final values of the lengths of the executive links  $l_{ik}$  are considered. The lengths of actuators are related to the lengths of the links of the master by the scale factor  $\lambda$ , i.e.  $l_i = \lambda \cdot l'_i$ .

Further, we set the increment of the coordinates along the arc of the trajectory  $S_i = S_i + V_i \Delta t$  and find the current values of  $l_i$ , after that the motion along the trajectory is effected. If the divergence between the actual and the specified trajectories is within the permissible error  $\varepsilon$ , then there is a further increment in time of movement  $t$  and a further increment of the arc coordinate  $S$ , if  $|l_i - l^*_i| > \varepsilon$ , then the arc coordinate is corrected. The movement along the trajectory is carried out until the current values of the lengths of the  $l_i$  actuators reach the specified final position of the  $l_{ik}$ .

As a result of the implementation of the proposed algorithm the trajectory of the load  $\lambda z = f(\lambda_x, \lambda_y)$  is defined, as well as the sequence of switching on the working cylinder's engines. Depending on the specified error of the deviation  $\varepsilon$  from the reproducible trajectory, the values of the steps  $\Delta s$  and  $\Delta t$  are selected.

The presented above control algorithm was implemented on the developed device for manual control of the loading manipulator-tripod (Fig.5), which allows to control not each degree of mobility separately, but directly several generalized coordinates, setting the trajectory of the output link. Management of actuators is effected through manipulation of the handle, through which the operator acts on the positioning sensors [12].

In experimental studies of this control system control actions were set by the operator and the ideal trajectory tracking is possible only if the speed of the control action is less than the maximum possible speed of the actuator rod movement.



**Figure 5.** The model of the ergonomic copying control system of the manipulator.

#### 4. Conclusion

The proposed method of controlling the electric cylinders of the loading manipulator is practically implemented and used in the manual control system of manipulators-tripods.

Experimental studies have shown that the deviation of the actual trajectory of the cargo's movement from the trajectory set by the operator does not exceed 3.4%, and the positioning error of the load is not more than 1.8%.

The developed control system allows to set the movement of the cargo directly, what could increase the productivity of loading and unloading operations with piece cargoes up to 18% when moving along straight trajectories.

When moving the cargo in a straight line with the simultaneous operation of the executive cylinders, the total work for the operation cycle is lower by 10-12% than when moving it from the same starting to the same final position with the work of each electric cylinder one-by-one.

### Acknowledgments

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