Control system for experimental model of robotic mobile platform with manipulator

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ABSTRACT

The control system for a robotic mobile platform with a manipulator witch that moves on orthogonal routes is considered in this work. To ensure the required speed and accuracy of the platform positioning, the method for changing the speed of the drive stepper motors is proposed. Features of the manipulator control system are considered. Methods of eliminating collisions during the movements in several mobile platforms on the marked surface are offered.

Keywords: robotic mobile platform, orthogonal routes, control system, manipulator, speed control, elimination of collisions

1. Introduction

Robotic mobile platforms are being increasingly used in the automation of technological processes. In the production process, one of the important tasks is to move components or materials in the territory of a shop or warehouse. For the uniformity of movements of bulk materials, liquids, and small details, it is expedient to use standardized containers. Various robotic mobile platforms that are equipped with manipulators have been developed and widely used to automate the movements of such containers and their placements on racks (Shneier, Bostelman 2015). The main requirements for developing and improving such platforms are to ensure high positioning accuracy and the required speed of movement on specified routes. When moving mobile platforms on arbitrary trajectories, ensuring these requirements is associated with the complexity and increases in the cost of control systems, which hinders the widespread introduction of such platforms. To simplify the control system and traffic planning, an experimental model of a robotic mobile platform for moving on orthogonal routes was proposed in Mazur and Panchak (2021). The possibility of the joint movement of several such platforms on a common marked surface provides an advantage of the mobile platform over other alternative variants for moving a manipulator with a container (on the principle of crane-beams or 3D CNC machines). The use of stepper motors and toothed rails in these variants allows for the high speed of a carriage with a manipulator and the accuracy of the container positioning; however, they involve moving only one container and do not allow for the use of multiple manipulators when crossing their trajectories. A kinematic scheme of a mobile platform manipulator was considered in Mazur (2021), as was ensuring the accuracy of its positioning when moving containers.

Since the mechanical part of a mobile platform significantly depends on the masses of containers and the speeds of their movements, the main attention in this work was paid to studying and improving the control system of a mobile platform. In particular, this paper considered the problems of providing the movement of a platform with variable speeds to increase the accuracy of the positioning and ensure the joint movement of several platforms.

The purpose of the current work is to improve the control system for robotic mobile platforms with a manipulator and develop methods for planning their joint movements on orthogonal routes based on research of an experimental model.

To achieve this goal, the following tasks were solved in the work:

1) The development of methods for improving the positioning accuracy of the mobile platform on orthogonal routes based on controlled changes of the speeds of drive stepper motors.
2) Further improve route-planning methods to avoid collisions of multiple platforms that move together on a common marked surface.

2. Stepper motor speed control

Eliminating dynamic overloads and skipping steps (to ensure the required positioning accuracy) are based on the controlled smooth change of a stepper motor's speed (Fig. 1).

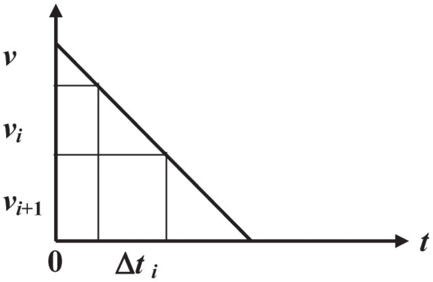


Fig. 1. Dependence of speed on pulse duration

To determine pulse duration Δt_i, which varies for each step of the motor during deceleration and acceleration, the following formula is proposed:

$$v_{i+1} = v_i + a \times \Delta t_i \tag{1}$$

where:

a – set deceleration (-3 cm/s^2),
v_i – initial value of platform speed ($v_i = 3$ cm/s),
v_{i+1} – value of platform speed after time Δt_i.

The distance s that the platform passes in one step of the motor is as follows:

$$s = \frac{(v_{i+1} + v_i) \times t_i}{2} = \frac{\pi \times d \times n}{k} \tag{2}$$

where:

d – diameter of wheel (38 mm),
n – number of gearbox shaft revolutions per second (0.25 rps),
k – number of pulses per one revolution of motor shaft (512 ppr).

At the specified values of d, n, k for the selected stepper motor with a reducer, the value of s will be equal to 0.058 mm/step.

Using Relationships (3) and (4), an array of Δt_i values ($i = 1$ to 256) are determined; these are used by the controller to generate pulses.

$$a \times \Delta t_i^2 + 2 \times v_i \times \Delta t_i - 2 \times s = 0 \tag{3}$$

$$\Delta t_i = \frac{-v_i + \left(v_i^2 + 2 \times s \times a\right)^{\frac{1}{2}}}{a} \tag{4}$$

Step motor pulse duration Δt_a, Δt_d and change of equivalent speed v_a, v_d (when accelerating and decelerating the mobile platform) are shown in Figure 2.

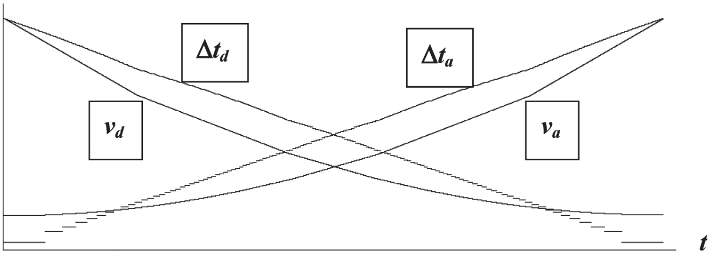


Fig. 2. Duration of stepper motor pulses and change in equivalent speed during acceleration and deceleration of the moving platform

3. Collisions elimination of several platforms

To plan the movements of several platforms and eliminate collisions between them, the marked surface is divided into zones of a size of 21 cm × 21 cm (Fig. 3). The size of the zone is determined by the size of the mobile platform (after taking a gap of 0.5 cm into account). The size of the buffers for storing 24 containers is 20.5 cm × 20.5 cm. To replenish the storage and issue containers to users, terminals of 20.5 cm × 4 cm are used with a capacity of five containers. Mobile platforms provide the movements of the containers between the terminals and buffers (while storing them in the warehouse) or between the buffers (the movements of containers between workplaces).

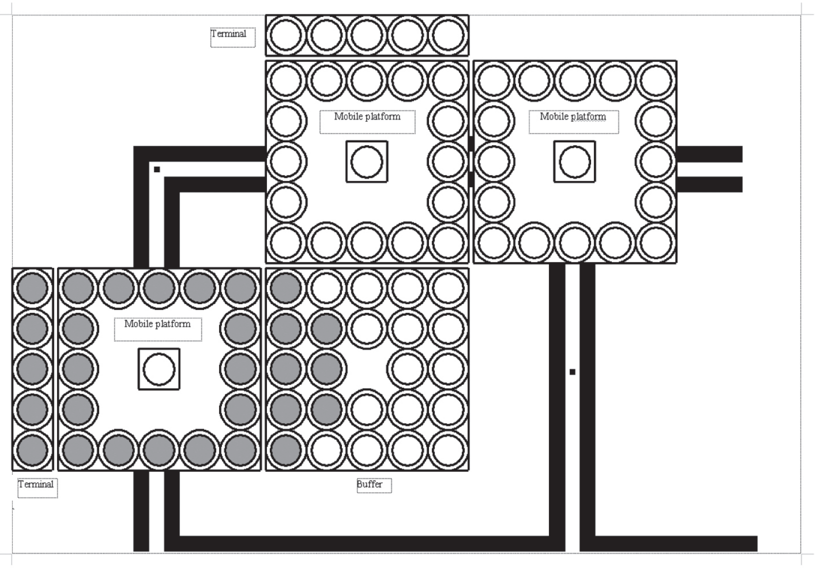


Fig. 3. Division of marked surface into zones

Appearance of manipulator with containers is presented in Figure 4.

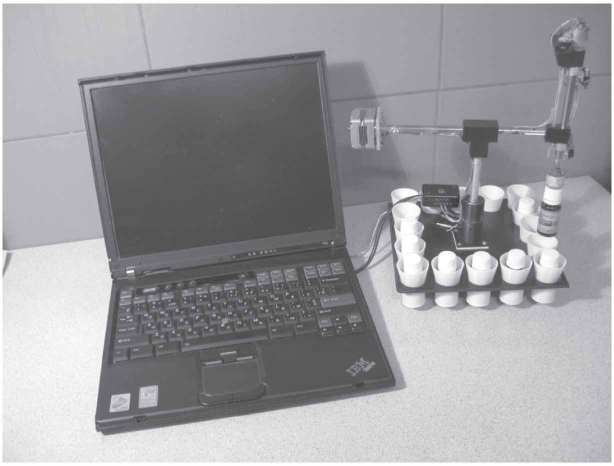


Fig. 4. Manipulator construction for mobile platform with containers

The proposed kinematic scheme of the manipulator (see Mazur 2021) provides the movements of the containers in 3D space and the required accuracies of their positioning.

The required angle of rotation of the vertical axis is provided by a stepper motor with a step of 0.9 deg. The length of the retractable horizontal beam is changed by using a stepper motor and a worm gear with an accuracy of 0.5 mm (after taking the backlash into account). The movement of the vertical retractable rod at the end of the beam is carried out by a servomotor with using tactile sensors. The electromagnet at the end of this rod ensures the captures and releases of containers with metal lids.

The process of moving the containers consists of two cycles:

1) At the giving of a control starting pulse and the switched-off electromagnet by means of the stepper motors, the necessary horizontal coordinates of a vertical rod are established. Then, the rod is lowered to the contact of the electromagnet with the container lid (which is fixed by a tactile sensor). The electromagnet is turned on, and the container is captured. Then, the rod rises to the upper position (which is determined by the limit switch).
2) By means of the stepper motors, the new position of the rod is established, and its lowering to contact of the container with a bottom of a nest (which is fixed by the tactile sensor) is carried out. The electromagnet is switched off, and the rod rises to the upper position.

To limit the length of the retractable horizontal beam of the manipulator (which determines the accuracy of the positioning of the container) only those containers in the buffer that are near the mobile platform are loaded and selected (see Fig. 3). The accurate positioning of the platform that is opposite of the buffer or terminal is provided by markers (the distance between which is 21 cm). Markers also provide the accurate positioning of the platform at intersections to change the directions of movements by 90 degrees.

The temporal-spatial relationships that describe the movement of the platform between the markers are presented in Figure 5. If the platform moves from one marker to an adjacent one, the movement time is 8 s (1 s is a movement with an acceleration of 3 m/s^2, 6 s is a movement with a nominal speed of 3 m/s, and 1 s is a movement with a deceleration of -3 m/s^2). If the platform moves between two markers without stopping at the nominal speed of 3 m/s, then the movement time is 7 s. The alignment of the platform centers and the marker is carried out to eliminate possible deviations that can be caused by wheel slippage by using an optical sensor during any additional time.

The route-planning and synchronization for multiple platforms is based on the approach that was proposed in Mazur (2013). All of the selected zones of the marked surface are divided into two groups: zones of intersections, and zones of buffers. In the zones of intersections, it is possible to change the directions of the platform movements by 90 degrees. Loading containers in buffers B or terminals T from the mobile platform is carried out by the manipulator when it is in the center of one of the zones of buffers. The centers of all of the zones are marked with markers that are recognized by an optical sensor. Each zone is determined by indices Z (i,j) (i is the row number, and j is the column number).

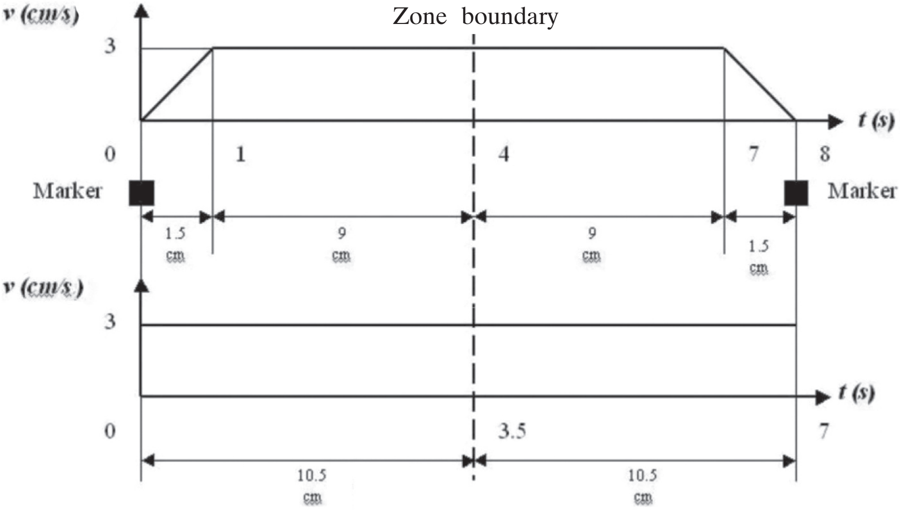


Fig. 5. Changing speed of mobile platform between markers

Depending on the location of the starting and ending points, the following options are possible for routing (Fig. 6):

- If the initial and final points are in adjacent zones Z (1, 1) and Z (1, 2) (Variant a), then the relocation is carried out in 8 s in accordance with Figure 5.
- If initial point Z (5, 2) and final point Z (5, 4) are on the same line horizontally (Variant b) or vertically, the relocation is carried out in $k \times 7 + 8$ s (k is the number of transit zones that the platform crosses at the rated speed without stopping).
- If initial point Z (3, 2) is on a horizontal line and final point Z (2, 1) is on a vertical line, then the direction of the platform movement is changed by 90 degrees within 1 s in zone of their intersection Z (3, 1) (Variant c).
- If initial point Z (4, 3) is on a vertical line and final point Z (1, 4) is on a horizontal line, then the direction of the movement is changed by 90 degrees (also within 1 s) in zone of their intersection Z (1, 3) (Variant d).
- If one of the coordinates of the zones of initial point Z (5, 6) and final point Z (1, 6) of the route are the same, then we have two equivalent routes with two zones of the direction change at the intersections: for Variant e, there are zones Z (5, 5) and Z (1, 5); for Variant f, there are zones Z (5, 7) and Z (1, 7). The choice of one of these two routes is made according to additional criteria.
- If the coordinates of initial point Z (5, 2) and final point Z (1, 6) are different (Fig. 7), there may be several routes that are identical in length (Variants a and b) that connect these points with the two zones of the direction change. The choice of one of them is made by taking possible collisions with other routes into account (for example, Route c).Thus, Route a is chosen, which in a zone of intersections that does not intersect with other previously laid routes in general (or during an intersection crossing).

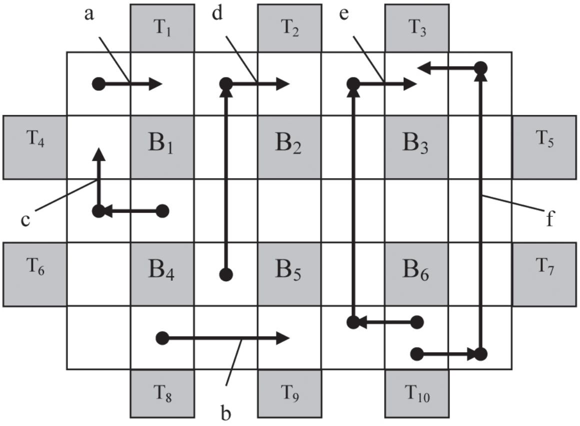


Fig. 6. Typical variants of orthogonal routes

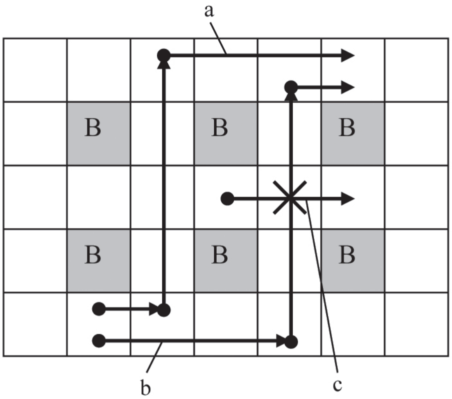
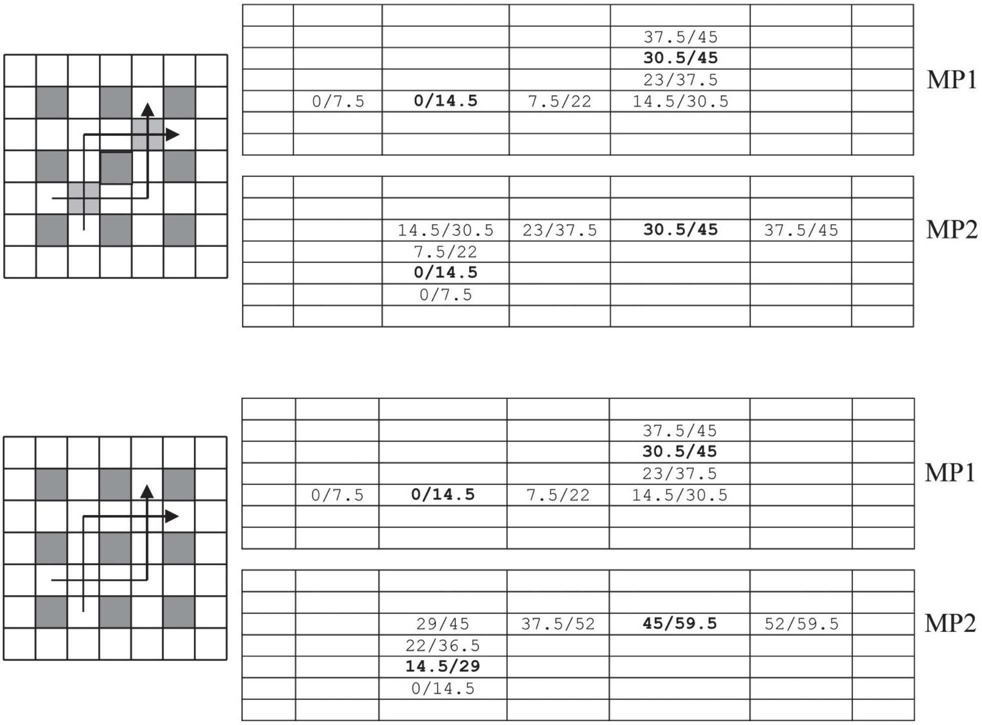


Fig. 7. Several orthogonal routes between specified points

Increasing the number of mobile platforms can increase the performance of the transport system, which is determined by the number of containers that are moved in a given amount of time. However, the probability of collisions increases with an excessive number of platforms; this can lead to additional delays and declining productivity.

Centralized planning is performed on the central computer of the transport system. At the same time, mobile platforms move according to the schedules that are received from a central computer (which provides traffic planning without collisions). For the centralized planning and synchronization of the joint movements of several platforms, a matrix model is proposed that ensures the elimination of collisions due to additional controlled delays.

When planning a movement, matrix M (i, j, m) is formed in which the model time of the beginning and end of platform [m/s] location in zone Z(i, j) are fixed. The time of the platform location in zone Z (i, j) is determined on the basis of the real time of platform move beginning *ts*, acceleration time *ta*, time of movement with nominal speed *tv*, deceleration time *td* (see Fig. 5), time of platform turn at the intersection *tm* ($tm = 1$), time of the container loading/unloading *tc*, and adjustment time *tu* (alignment of the platform center with the center of the marker). Additional delay time *tz* is introduced to eliminate collisions based on an analysis of the matrix. The elimination of collisions due to the introduction of additional delays *tz* ($tz = 14.5$) is shown in Figure 8.



				37.5/45		
				30.5/45		
				23/37.5		
	0/7.5	**0/14.5**	7.5/22	14.5/30.5		

MP1

		14.5/30.5	23/37.5	**30.5/45**	37.5/45	
		7.5/22				
		0/14.5				
		0/7.5				

MP2

				37.5/45		
				30.5/45		
				23/37.5		
	0/7.5	**0/14.5**	7.5/22	14.5/30.5		

MP1

		29/45	37.5/52	**45/59.5**	52/59.5	
		22/36.5				
		14.5/29				
		0/14.5				

MP2

Fig. 8. Matrix model for collision elimination

4. Conclusions

The following new scientific and practical results were obtained in this work:

- A method for providing necessary positioning accuracy based on the movements of a mobile platform with variable speeds has been proposed.
- A control system for the manipulator to move containers has been developed.
- A matrix model for eliminating conflicts during the joint movements of several mobile platforms on a marked surface has been developed.

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