Experimental Model of a Mobile Platform for Moving on Orthogonal Routes

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Abstract. The paper considers an experimental model of a mobile platform for moving on orthogonal routes. The advantages of orthogonal routes for planning and ensuring the movement of the platform are shown. The structural scheme of the mobile platform and the organization of functioning of its subsystems are developed. The platform's construction and digital control system for ensuring its motion and positioning on the marked surface are offered. Methods of traffic organization and routes planning for platform movement are proposed. Peculiarities of using the experimental model of the platform in the educational process of the CAD Department are considered.

1. Introduction

Mobile platforms are an important component of modern robotic systems. Many theoretical works and practical developments are devoted to various aspects of creating such platforms [1, 2]. One of the promising areas that is currently developing intensively is the further intellectualization of mobile platforms, which ensures their movement along arbitrary trajectories [3-6]. In some cases, this expands the capabilities of such platforms, but leads to further complication of control systems and an increase in their cost. In addition, when using several platforms on the same route network, the task of controlling their joint movement in a limited space becomes much more complicated due to mutual interference [7]. At the same time, for solving a number of practical problems, the introduction of certain restrictions is quite acceptable, which makes such platforms simpler and cheaper. One of the possibilities for introducing such restrictions in this work is the transition from movement along arbitrary routes to the movement of platforms on orthogonal routes. This reduces the cost of the mobile platform control system and simplifies the routes planning and synchronization of mobile platforms movement when they move together. In our opinion, some aspects of creating mobile platforms for moving on orthogonal routes and planning such routes have not been sufficiently studied. This determines the relevance of such research. Therefore, the problem of creating an experimental model of a mobile platform for researching its movement on orthogonal routes is posed and solved in this work.

The purpose of the work: Development of the structure, construction and control system of the experimental model of a mobile platform for movement on orthogonal routes.

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

- The development of the kinematic scheme and construction of the platform.
- The development of the general structure of the mobile platform control system and definition of its main components.
The development of methods and control systems to ensure the movement of the platform on orthogonal routes.

Development of methods of route planning on an orthogonal route network.

2. The development of the kinematic scheme and construction of the platform

The main task which is solved by the developed mobile platform is to provide controlled movement on the planned route. To do this, it is proposed to use an orthogonal route network, which provides deterministic movement of the mobile platform, simplifies route planning and provides for a discrete change of direction at intersections. The trajectory of the mobile platform is determined by the marking on the traffic surface, which determines the configuration of the route network. The construction of the mobile platform includes a mechanical part that implements the kinematic scheme of the platform and an electronic part that implements a digital motion control system of the platform. The experimental model of the mobile platform placed on the marked surface is presented in Figure 1.

The proposed kinematic scheme of the platform is presented in Figure 2. It consists of two independent drive units equipped with controlled servo drives (SG92R), to change the direction of the platform movement. Digitally controlled servo drives provide synchronous turn of drive and passive wheels by ±90 degree when changing the direction of the platform movement, as well as turn of these wheels from the main direction by ±15 degree to compensate the deviations of the platform from the trajectory specified by the marking lines. The drive wheel of each drive unit is equipped with the stepper motor with a reducer (28BYJ-48) and provides the controlled movement of the platform on a route with the set speed. The wheel layout of each unit provides independent displacement of the front and rear of the platform based on signals from optical sensors that track the marking lines. Changing the direction of movement by ±90 degree is carried out for a motionless platform at the intersections of the route network. One of the advantages of the proposed kinematic scheme is that platform orientation does not change when changing the direction of platform movement at 90 degree. That is, the coordinate system of the platform coincides with the coordinate system of the plane on which it moves. This simplifies the system of external control of the manipulator, which a mobile platform can be equipped.
3. The development of the general structure of the mobile platform control system

The digital control system for the mobile platform provides the solution of two main tasks: change of the direction of the platform movement and controlled movement of the platform on the certain distance with the set speed. Changing the direction of the platform movement includes changing the main direction of movement by ±90 degrees at intersections and periodically changing the direction of movement by ±15 degrees from the main direction to automatically track marking lines and correct deviations from the trajectory specified by the route. The general structure of the mobile platform control system is presented in Figure 3. It consists of two subsystems: the subsystem for controlling the change of movement direction and the subsystem for controlling the movement of the platform. Changing the direction of movement of the front and rear of the platform is carried out using servo drives (SD), which change the angle of rotation of the wheels by ±90 degrees or ±15 degrees. The formation of control pulses for servo drives is provided by control pulses shaper for servos (CPSS) using pulse-width modulation (PWM). The formation of deviation signals from the marking lines is carried out by the sensors unit (SU). The sensors signal switch (SSS) switches groups of signals depending on the direction of the platform movement. Control signals to change the direction of movement by ±90 degrees and ±15 degrees are generated by the microcontroller based on the route description and signals from the sensors unit. The platform movement control subsystem consists of two driving stepper motors (SM). The formation of the pulse sequence for the half-step mode of stepper motors operation is carried out by control pulses shaper for stepper motors (CPSSM). The speed and direction of rotation the shaft of stepper motors is determined by the control signals coming from the microcontroller (MCU). The generated pulses are fed to the stepper motors drivers (SMD). Centralized route planning for one or more mobile platforms is provided by a personal computer (PC), which transmits the necessary information to the MCU. For the experimental model of the mobile platform the personal computer performs the functions of the MCU.
4. Control system for changing the direction of the platform movement and tracking a given trajectory

Changing the direction of movement of the platform and tracking a given trajectory is carried out by servo drives with digital control. Each servo provides synchronous turn of the drive and passive wheel by ±90 degrees to change the moving direction of the platform at the intersection of routes and change the angle of rotation of the wheels by ±15 degrees from the main direction to compensate the deviations from the specified trajectory during the platform movement along the route. The electrical diagram of the control system is shown in Figure 4. Pulse width modulation (PWM) is used to control the servo. The proposed control circuit consists of a generator of synchropulses with a period of 20 milliseconds, implemented as a multivibrator based on the timer DA1 NE 555. The synchropulses are fed to a pulse-width modulator implemented on the basis of a singlevibrator (chip DA2 NE 555), which generates pulses with a given duration. These pulses are fed to the control input of the servo. The pulse duration is determined by the time constant of the RC-link formed by the capacitor C3 and a set of resistors R7-R10. Resistors R7, R8 and R9 shunted by diode-transistor optocouplers (EL817) to change the time constant and generate control pulses of different duration. The optocoupler are controlled by digital input signals \( K_1, K_2, K_3 \). The relationship between the angle of rotation of the servo and the duration of the control pulses is shown in Figure 5. Provision of 12 necessary directions of movement is carried out by changing the angle of rotation of the wheels (signals \( K_1, K_2, K_3 \)) and the direction of the stepper motors rotation (signal \( D \)). The values of the signals to ensure the specified direction of movement \( N \) are presented in the correspondence table 1.

The reflective optical sensors system S1-S8 (TCRT5000) is used to detect the deviations of the mobile platform from the trajectory set by the black and white marking lines (Figure 6). Signals from optosensors are fed to the Schmidt trigger, which improves the shape of digital signals and provides the hysteresis needed to eliminate self-oscillations of the tracking system at the boundary of the black and white marking lines. When moving in the direction, indicated by the arrow, sensors S1 and S2 detect the deviation of the front part of the platform (to left or to right), and sensors S3 and S4 detect the deviation of the rear part of the platform. Based on the signals \( S_1-S_4 \) from the optosensors S1-S4, taking into account the direction of rotation of the stepper motor \( D \), the signals \( K_1-K_3 \) are determined (in accordance with table 2) to generate width-modulated pulses. These pulses control the servos SD1 and SD2. When moving in the perpendicular direction, switching to sensors S5-S8 is performed by sensors signal switch SSS. The values of the signals \( K_1-K_3 \), which provide the formation of width-modulated pulses for servos SD1 and SD2 depending on the signals \( S_1-S_4 \) of the optosensors S5-S8 and the direction of rotation of the stepper motor \( D \), are presented in table 3. Automatic tracking of marking lines ensures the coincidence of the coordinate system of the mobile platform and the marked traffic surface.
Table 1. Control signals to provide the required directions

|   |   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 1 | 1 | 7 | 1 | 1 | 1 | 1 |   |   |
| 2 | 0 | 0 | 1 | 1 | 8 | 1 | 0 | 1 | 1 |   |   |
| 3 | 0 | 0 | 1 | 0 | 9 | 1 | 0 | 1 | 0 |   |   |
| 4 | 0 | 1 | 0 | 1 | 10| 1 | 1 | 0 | 1 |   |   |
| 5 | 0 | 0 | 0 | 1 | 11| 1 | 0 | 0 | 0 |   |   |
| 6 | 0 | 0 | 0 | 0 | 12| 1 | 0 | 0 | 0 |   |   |

Figure 4. Electrical circuit for the formation of the servo control pulses.

Figure 5. The width of the control pulse of the servo to provide the necessary directions of movement.
Table 2. Control signals to provide the required directions

| $S_1$ | $S_2$ | $D$ | $K_1$ | $K_2$ | $K_3$ | $N$ | $SD$ | $S_3$ | $S_4$ | $D$ | $K_1$ | $K_2$ | $K_3$ | $N$ | $SD$ |
|-------|-------|-----|-------|-------|-------|-----|------|-------|-------|-----|-------|-------|-------|-----|------|
| 1     | 1     | 0   | 0     | 1     | 1     | 2   | 1    | 1     | 1     | 0   | 0     | 1     | 1     | 2   | 2    |
| 0     | 1     | 0   | 0     | 0     | 1     | 0   | 3    | 1     | 0     | 0   | 1     | 0     | 0     | 1   | 3    |
| 1     | 0     | 0   | 1     | 1     | 1     | 1   | 1    | 0     | 0     | 1   | 1     | 1     | 1     | 1   | 2    |
| 1     | 1     | 1   | 0     | 1     | 1     | 8   | 1    | 1     | 1     | 1   | 0     | 1     | 1     | 8   | 2    |
| 0     | 1     | 1   | 1     | 1     | 1     | 7   | 1    | 0     | 1     | 1   | 1     | 1     | 1     | 7   | 2    |
| 1     | 0     | 1   | 0     | 1     | 0     | 9   | 1    | 1     | 0     | 1   | 0     | 1     | 0     | 9   | 2    |

Table 3. Control signals to provide the required directions

| $S_5$ | $S_6$ | $D$ | $K_1$ | $K_2$ | $K_3$ | $N$ | $SD$ | $S_7$ | $S_8$ | $D$ | $K_1$ | $K_2$ | $K_3$ | $N$ | $SD$ |
|-------|-------|-----|-------|-------|-------|-----|------|-------|-------|-----|-------|-------|-------|-----|------|
| 1     | 1     | 0   | 0     | 0     | 0     | 5   | 1    | 1     | 1     | 1   | 0     | 0     | 0     | 1   | 5    |
| 0     | 1     | 0   | 0     | 0     | 0     | 6   | 1    | 0     | 1     | 0   | 0     | 0     | 0     | 0   | 6    |
| 1     | 0     | 0   | 1     | 0     | 1     | 4   | 1    | 1     | 1     | 0   | 0     | 1     | 0     | 1   | 4    |
| 1     | 1     | 1   | 0     | 0     | 1     | 11  | 1    | 1     | 1     | 1   | 0     | 0     | 1     | 11  | 2    |
| 0     | 1     | 1    | 1   | 0     | 1     | 10  | 1    | 0     | 1     | 1   | 1     | 0     | 1     | 10  | 2    |
| 1     | 0     | 1   | 0     | 0     | 0     | 12  | 1    | 1     | 0     | 1   | 0     | 0     | 0     | 0   | 12   |

5. Positioning and motion control system of the mobile platform

The movement of the platform is carried out on the route specified by rectilinear orthogonal segments that run on the marking lines. The end coordinates of these segments correspond to the points of beginning and end of the movement, as well as intermediate points on crossroads, where change the direction of movement of the motionless platform. For each segment, the change of speed is carried out in accordance with the graph shown in Figure 7.
The zone of acceleration, deceleration zone and zone of movement with nominal speed are allocated. The change in speed is carried out by changing the frequency of the pulses that are fed to the drivers of the drive stepper motors from the shaper CPSSM. The input signals for CPSSM are the signals of the direction of rotation of the stepper motor D and the synchropulses C of the variable frequency. The formation of signals C and D is carried out by the program of the microprocessor MPU, which implements a mathematical model of platform motion based on the description of the route. This provides for uniformly accelerated and uniformly decelerated motion of the platform at the beginning and end of the segment. This is necessary to eliminate skipping of the stepper motor steps and slipping of the platform wheels. In the middle part of a segment uniform movement is carried out with speed which is defined by nominal speed of rotation of a shaft of the stepper motor reducer (0.25 turns/sec for the 28BYJ-28 engine). With a wheel diameter of 38 mm, this provides a nominal speed of 3 cm/sec. With the selected value of acceleration \( A = 3 \text{ cm/sec}^2 \), the acceleration and deceleration time is 1 sec. With a reduction factor of 1/64, the nominal speed of the stepper motor shaft rotation is 16 turns/sec (1024 steps/sec for half-step mode). Uniform acceleration (deceleration) occurs over 512 steps and an decrement (increment) of the period of pulses is equal 3.8 ms. The distance \( L_a \) passed by the platform during acceleration (deceleration) is 1.5 cm. If the length of the segment \( L > 2 \times L_a \), the time \( T_n \) of movement at nominal speed \( V_n \) is

\[
T_n = (L-2\times L_a)/V_n
\]  

(1)

The total time \( T_s \) of movement between the start and end points of the segment will be equal

\[
T_s = V_n/A + L/V_n
\]  

(2)

At the length of the segment \( L \leq 2 \times L_a \), the acceleration (deceleration) time is

\[
T_a = (L/A)^{1/2}
\]  

(3)

The achieved maximum speed \( V_m \) will be equal

\[
V_m = A \times T_a
\]  

(4)

The total number of steps \( K \) of the engine 28BYJ-28 (in half-step mode) for the passage of a segment of length \( L \) (in centimeters) is

\[
K = L/0.0029
\]  

(5)

The obtained ratios are necessary to determine the frequency and number of synchropulses in the formation of control pulses for stepper motors. They also provide the determination of the time of passage of the route crossroads (without stopping), which is necessary to synchronize the routes of the two platforms in order to eliminate collisions. The issues of planning and synchronization of routes of several platforms on the basis of the approaches presented in [8] are considered in more detail in a separate work. Determining the required number of engine steps to pass a given path does not provide accurate positioning of the platform due to wheels slippage. Therefore, the system provides the clarification of the position of the platform through the use of calibration markers on the marked surface, which are detected by the sensor S9. The signals of this sensor are processed by the MPU to refine and redefine the required number of steps.

Figure 7. The variation of speed on route segments.
Another problem solved by the platform motion control system is the exact positioning of the platform at the crossroad to change the direction of movement. To do this, for the direction of movement indicated by the arrow, optosensors S5-S9 are used. Sensor S9 captures the crossroad marker (with size 5×5 mm) and sensors S5-S8 provide accurate positioning of the platform at the intersection to change the direction of movement by 90 degrees for a motionless platform. When moving in the perpendicular direction, the signals of sensors S1-S4 and S5-S8 change places using sensors signal switch (SSS).

6. The use of the experimental model of a mobile platform in education process of CAD department
The planned use of the developed mobile platform in the process of diploma and course design by students of CAD Department involves solving the following tasks:

- Study and improvement of the structure and functional elements of the mobile platform.
- Research of dynamic characteristics of the mobile platform.
- Research of the tracking system for observance of a trajectory of movement on the set route.
- Research of the positioning system of the mobile platform and control of its movement.
- Planning and synchronization of routes for joint movement of platforms on the route network.
- Design and manufacture of platform components using 3-D printers and CNC machines.

Conclusion
In this work the following scientific and practical results are received:

- The kinematic scheme of the platform, which provides movement on orthogonal routes and tracking of the set trajectory of movement, is developed and realized.
- The structure of the digital control system of the mobile platform has been developed.
- The control subsystem of change the direction of movement and tracking of the trajectory, which set by lines of a marking, is developed and realized.
- The control subsystem of platform positioning and its movement with the calculated speed is developed and realized.

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