Development of Control System of Mobile Robot With Differential Drive

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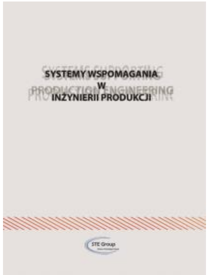

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Abstract: Currently, the topic of automation of logistic processes in warehouses is relevant. The article considers a control system of high level for a mobile robot with a differential drive with a maximum payload of 200 kg with motion simulation in the Matlab Simulink software product. Optimal control of drives based on brushless DC motors at the lower level has been developed. The transient time of low level control system is 1.067 seconds. The mobile robot control system in the minimum version consists of ten ultrasonic distance sensors located along the perimeter of the mobile robot body and of eight contrast band sensors.

Keywords: mobile robot, automation, control system, simulation

INTRODUCTION

The growth of robotics in the world has recently increased the level of entry into the field of robotics, broadens its field of knowledge, and in this regard, the level of requirements for robotic systems, including control systems, is growing.

Warehouse automation primarily affects processes that require physical human intervention – moving goods and merchandise between storage, sorting and shipping areas. Consequently, mobile robots with an autonomous control system are a core component of automated warehouses. This means that autonomous mobile robots are significantly more efficient, since there is no need for constant monitoring by an operator. A modern control system must be as fast and energy efficient as possible. Examples of control systems and mobile robots can be found in the literature [7, 8, 10, 13].

This article discusses the control system of a mobile robot. In addition, the electrical circuit of the platform is considered, the interaction scheme of the controller and the NVIDIA single-board computer is described. The main problems arising in the design of mobile robots are analyzed, the ways of their solution are proposed [4].

The application of a group of specialized robotics systems is considered [1, 12]. The current state of control systems of single robot systems does not allow to solve all tasks set for a robot. The analysis of methods of control of a group of robots in real conditions was carried out. The necessity of using a multilevel control system for

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an intelligent robot was substantiated. The multi-level control system for intelligent robot is proposed. Such a system implies the possibility of controlling the robot in one of four modes: remote, supervised, autonomous and group mode. Moreover, each robot can be in any control mode depending on external conditions and its state. The application of this control technique is shown on the example of the motion of a group of robots with a front interval. The role of a group of robots moving behind a control robot is considered. The finite automata method was used in the formation of the robot control algorithm [1].

DEVELOPMENT OF MOBILE ROBOT CONTROL SYSTEM

The purpose is to develop a control system for a mobile robot with a differential drive in a deterministic environment and optimal control of drives based on commutatorless DC motors using a model-oriented approach in Matlab Simulink at the upper and lower levels [6].

The differential drive type involves two motor-wheels, hence the robot is controlled by varying the angular velocities of the wheels (upper level control). A Raspberry Pi single board computer is responsible for sensing the deterministic environment, while the STM32F405 microcontroller is directly responsible for applying the control action to the motors. This modular system principle makes it possible to calculate motion parameters as quickly and accurately as possible. By separating the tasks, the minimum required computing power is reduced and therefore the energy efficiency is increased.

The control of a brushless DC (BLDC) motor requires feedback. In this paper the position control of the BLDC motor is given. Hall sensors detect the rotor position and depending on this the control action is applied to the windings, which is obtained from a three-phase inverter consisting of a galvanic isolator to separate the power and signal parts, an upper and lower level key driver and MOSFETs.

A control system model in the form of transfer functions has been developed in Matlab Simulink. A DC brushless motor with a load is implemented as a submodel and as an ideal torque source. The model of the low-level control system for the BLDC motor is shown in Figure 1.

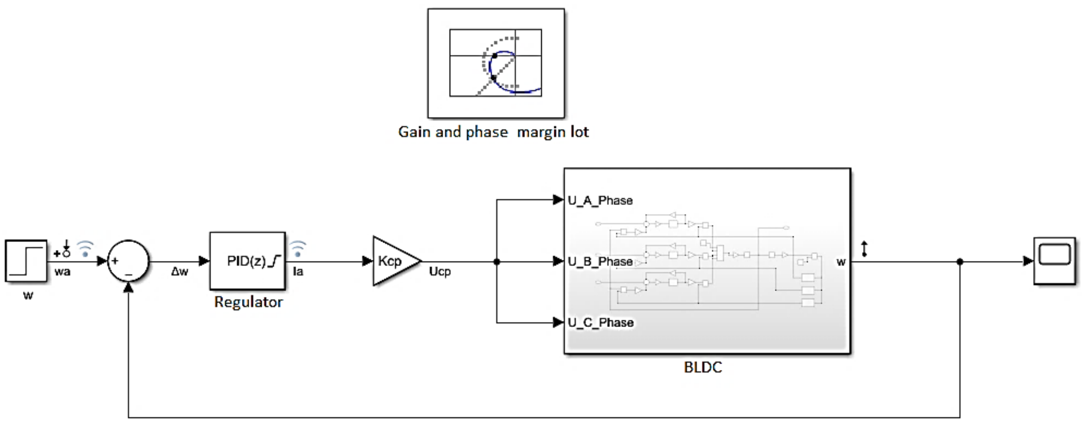

Fig. 1 The model of the low-level control system for the BLDC motor

Sub-model control system for the BLDC motor with load is shown in Figure 2.

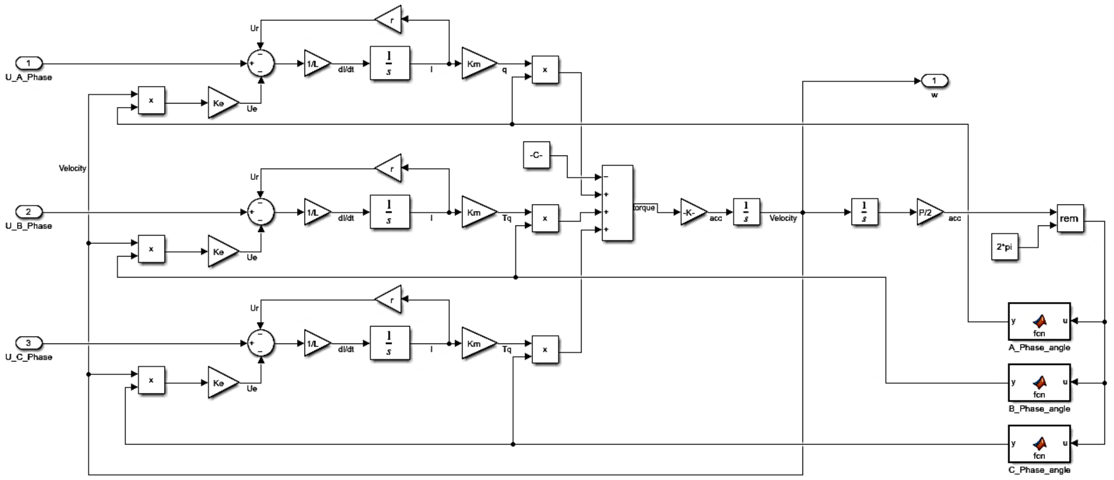

Fig. 2 Sub-model control system for the BLDC motor with load

The lower level control system for a BLDC motor is implemented as transfer functions in Matlab Simulink environment. The loadless BLDC motor has been implemented as a submodel and as an ideal torque source [11]. Simulation results with a synthesized PID control law based on a discrete model with a sampling time of 0.001 s. at a nominal angular velocity of 5 rad.s^{-1} is shown in Figure 3.

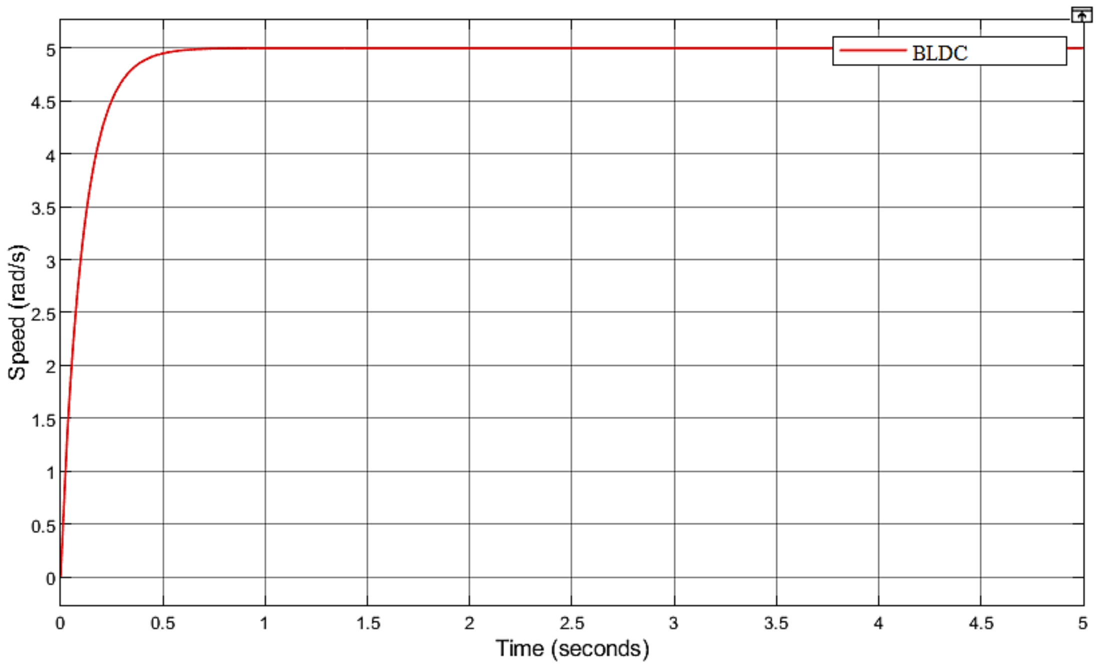

Fig. 3 Transient graph

The upper level control system of the mobile robot is developed based on the kinematic diagram in the horizontal plane shown in Figure 4.

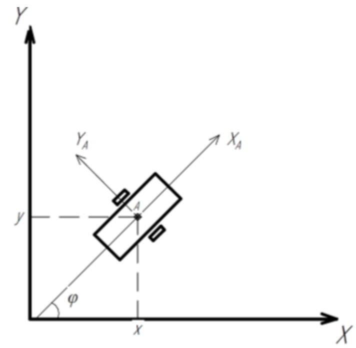

Fig. 4 Kinematic diagram in the horizontal plane

Point A (the initial position of the robot) has coordinates (xA, yA), and end point B has coordinates (xB, yB), axes XA, YA and XB, YB are local coordinate systems, and axes X and Y are the global coordinate system of the mobile robot. The angle φ is the angle between the local and global coordinate systems, ψ is the angle between the direction of motion of the mobile robot and the global coordinate system, θ is the angle by which the robot needs to turn, V is the linear speed of the robot.
The motion of the mobile robot in the horizontal plane is described by the following formulas [5]:

$$\begin{cases} \frac{dx}{dt} = \frac{(\omega_r+\omega_L)*r}{2} * cos\varphi; \\ \frac{dy}{dt} = \frac{(\omega_r+\omega_L)*r}{2} * sin\varphi; \\ \frac{d\varphi}{dt} = \frac{(\omega_r-\omega_L)*r}{W}; \end{cases} \quad (1)$$

$$\rho = \sqrt{(x_B - x_A)^2 + (y_B - y_A)^2}; \quad (2)$$

$$\psi = arctg\left(\frac{y_B - y_A}{x_B - x_A}\right); \quad (3)$$

$$\theta = \psi - \varphi; \quad (4)$$

$$\begin{cases} \omega_L = V - \theta; \\ \omega_r = V + \theta, \end{cases} \quad (5)$$

where:
ω_r and ω_L are angular velocities of the right and left wheels respectively,
r is the wheel radius,
ρ is the distance the robot has to move.

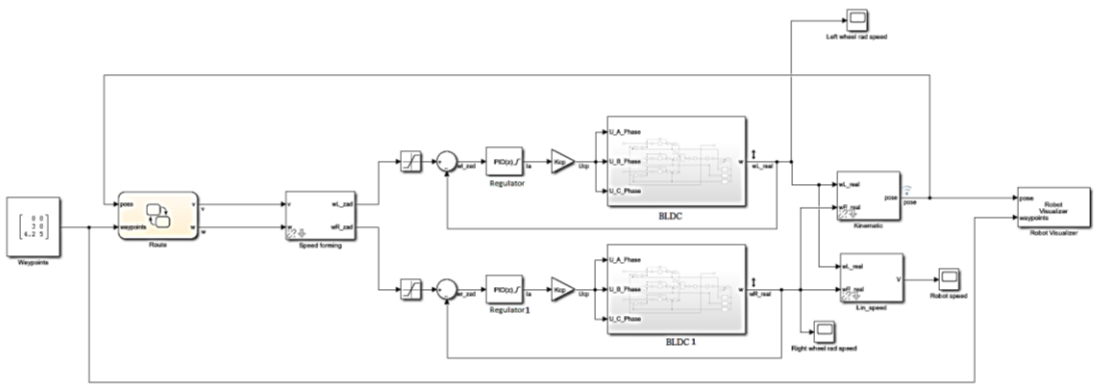

Fig. 5 Model for investigating the motion of a mobile robot

Using formulas (1)–(5) developed a model of a mobile robot with a differential type of drive in the software product Matlab Simulink [9] to study its motion, shown in Figure 5.

RESULTS

From the results of the motion simulation, it follows that the mobile robot has high manoeuvrability, which is a distinctive feature of differential drive. The maximum speed is reached in one second, which is a good dynamic performance among mobile robots, there is no overshoot and the system is stable. It can be seen in Figure 6 that the mobile robot has the ability to rotate 90 degrees in narrow spaces only 1.5 meters wide without stopping and then rotating in one place.

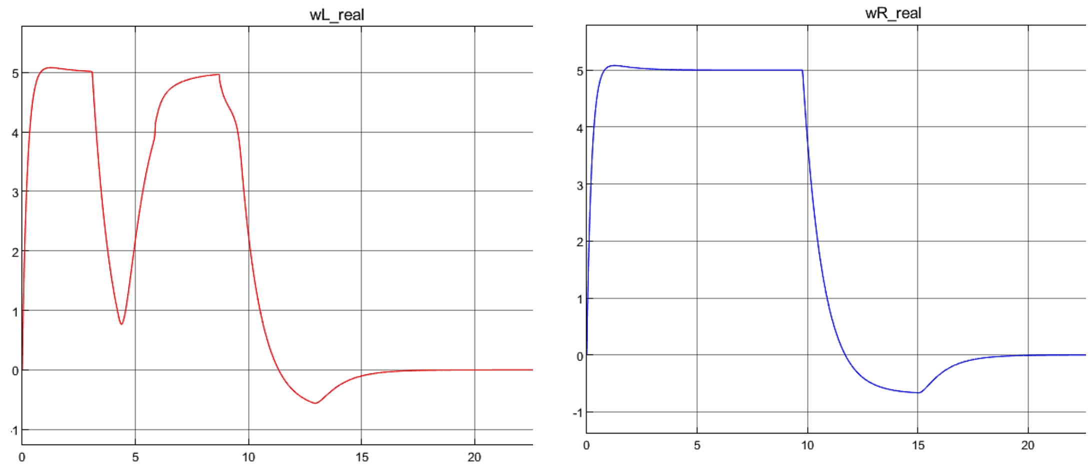

Fig. 6 Simulation of robot movement with a 90 degree turn (angular speed of the left-hand wheel and angular speed of the right -hand wheel)

The mobile robot with differential drive is optimal for basic manoeuvres in the warehouse environment, namely 90 degree turns, U-turns and straight-line movements (Figure 6).

CONCLUSION

Currently, there is a significant expansion of the use of automatically driven mobile robots in manufacturing companies, mainly for logistical purposes, but also for the handling of specific materials. A commonly used technique for navigation is the physical marking of the trajectories of the desired path of movement on the floor (optically, magnetically, by conductors in the floor or in another way). It can be used in production systems, where robots deliver parts, or replenish goods in warehouses, etc. These mobile robots are realized as pallet conveyors, tractors, conveyors of parts and materials and are used to operate assembly lines, etc. [2, 3] The submitted contribution deals with the control system of a mobile robot that can be part of automated warehouses.

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