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ROBOTIC MOBILE PLATFORM FOR CONTAINERS STORAGE SYSTEM

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Abstract. Unjustified concentration of intelligent control functions and means for loading/unloading operations and moving containers worsens the technical and economic performance of anthropomorphic robotic mobile platforms of the AMR (Autonomous Mobile Robot) class. In this work, a promising approach is proposed, which is based on the complex development of an automated containers storage system and a specialized robotic mobile platform to take into account the peculiarities and increase the efficiency of their joint operation. The proposed structure and organization of the automated containers storage system are considered in this work. For the effective functioning of this system, a specialized robotic mobile platform has been developed. An experimental model of the robotic mobile platform for researching the implementation peculiarities of its units and the control system is presented. The solutions to ensure the accuracy of platform and container positioning during their movement are proposed.

Keywords: containers storage system, robotic mobile platform, experimental model, positioning accuracy.

Introduction

Organized storage of components, materials and finished products is an integral part of many technological processes in industry and trade. Considering the labor-intensive nature of warehouse operations, their mechanization and automation is an urgent task. Electric trucks and forklifts are widely used when moving and storing bulky cargoes placed on pallets. Recently, there has been a significant increase in interest in automating the storage of cargoes weighing up to 50 kg, which prevail in assembly production and in retail trade. In order to unify operations of movement and storage of such cargoes, standardized containers are very often used. Today, robotic mobile platforms (RMPs) are widely used to automate the movement of containers [1]. However, the effectiveness of the operation of such platforms depends significantly on the containers storage system (CSS) in which they are used. In particular, traditional human-oriented CSS mainly involve the movement of cargoes on carts on the floor in the aisles between the racks. At the same time, the considerable width of these aisles leads to irrational use of warehouse space. The simultaneous movement of several robotic mobile platforms with containers also requires a significant width of these aisles. At the same time, it is necessary to solve complex tasks of recognizing, kneading and overtaking platforms, which makes their control system more expensive [2]. The use of the RMP proposed in [3], which move along orthogonal routes, allows to partially eliminating the indicated shortcomings.

In early CSS, the complexity of orientation and placement of containers in the cells of multi-level racks required the participation of a person to perform these time-consuming operations. To automate the process of placement containers in the cells and their withdrawal from them, modern RMPs are equipped with manipulators [4], [5]. However, the considerable weight and dimensions of such manipulators limit the dimensions of the working surface for placing containers and increase energy consumption, which limits the time of autonomous operation of the RMPs. Computer vision systems are used to control such manipulators. As a result, this leads to an increase in the complexity, dimensions and weight of the RMPs and their significant increase in cost [6]. These factors limit the possibilities of mass use of such RMPs for the automation of warehouse activities.

Unjustified concentration of intelligent control functions and means for loading/unloading operations and moving containers worsens the technical and economic performance of anthropomorphic robotic mobile platforms of the AMR (Autonomous Mobile Robot) class.

This paper proposes a promising, in our opinion, approach, which is based on the redistribution of functions and the complex development of an automated containers storage system (ACSS) and a specialized robotic mobile platform to take into account the peculiarities and increase the efficiency of their joint functioning.

Problem Statement

The purpose of the work is the development of an automated containers storage system and a specialized robotic mobile platform for moving containers during ACSS operation.

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

- development of the structure and organization of the containers storage system;
- development of an experimental model of a specialized RMP for moving containers;
- conducting experimental studies and making decisions to ensure the accuracy of RMP and container positioning during CSS operation.

Main Material Preentation

The proposed containers storage system contains two rows of racks (1), which consist of multi-level modules (2) formed by vertically placed cells (3) measuring 50*50*50 cm (Fig. 1).

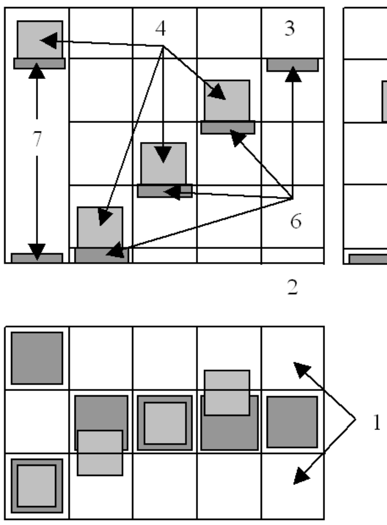

Fig. 1. The structure and organization of CSS

To move the container (4) a specialized robotic mobile platform (6) is used, which moves along the racks in aisle 50 cm wide (5) along two guides for each level (Fig. 2). Electrically isolated guides ensure accurate positioning of the RMP and its power supply. The RMP also displacement the container from the corresponding cell to move it to the working surface of one of the two elevators (7), which vertically moves the container to the required level. The vertical movement of this working surface of the elevator is ensured by means of four screws (placed at its corners), which are synchronously rotated by the motor in threaded bushings. To reduce the force of horizontal movement of the container, guides are installed on the lower part of its bottom, and two rows of bearings are installed on the working surfaces of the robotic platforms, elevators and cells. The use of only one robotic platform for each level of racks eliminates conflicts during the simultaneous movement of several platforms. The presence of two elevators reduces delays when loading containers into the storage system and issuing them to recipients. The dimensions of the container for storage of components, packaged and loose materials are 40*40*40 cm and are coordinated with the dimensions of the working surface of the Euro pallet (120*80 cm). At the same time, the height of the container can vary within 20-40 cm. The mass of the loaded container is up to 40 kg. The developed system ensures compact storage of containers. With the length of each of the two racks equal to 10 m and the total width of 1.5 m, the area occupied by the storage system is 15 m^2. At four levels, the system provides storage of 152 containers.

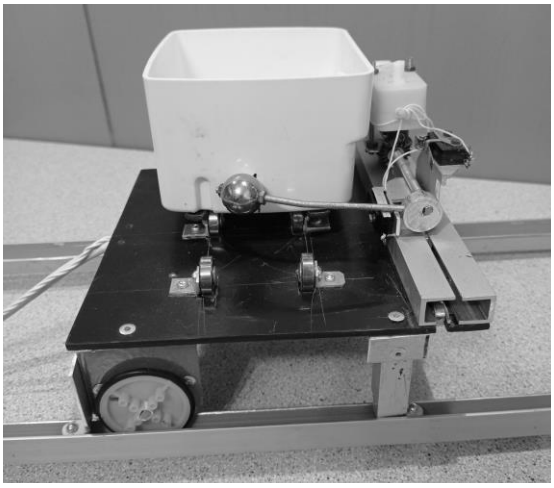

Fig. 2. The specialized robotic mobile platform

Results and Discussion

The movement of containers in the proposed CSS is carried out by a specialized robotic mobile platform. The final parameters and technical characteristics of this RMP are determined at the stage of designing a specific CSS. Therefore, an experimental model of the robotic mobile platform for researching the realization peculiarities of its units and the control system is developed.

The construction of the RMP experimental model is presented in Fig. 3. The RMP construction contains the following main units: a drive unit for moving the platform along the guides along the racks; a unit for gripping and holding the container when it is moved; a unit for shifting the container from the working surface of the platform to the cell of the rack or its displacement from the cell to the working surface of the platform.

In the experimental model of the RMP, the drive unit for moving the platform along the guides contains two stepper motors with a gearbox (1) and two drive wheels with rubber tires (2). Vertically placed bearings (3) are used as passive wheels on the opposite side of the platform. To center the wheels of the platform in the grooves of the guides, horizontally placed bearings (4) are used. The control system provides controlled synchronous rotation of the drive wheels using the control pulses of the stepper motors. The application of variable speed of platform movement provides limits on the amount of acceleration/deceleration to eliminate skipping of stepper motor steps. The initial positioning of the platform opposite the corresponding cell of the rack is provided by supplying the necessary number of pulses to the stepper motors. For further precise positioning within ± 1 mm, a reflective optical sensor [7] and a mechanical catcher are used. When designing the RMP, there is also a variant of the drive unit for moving the platform using one stepper motor and a gearbox with a two-way shaft extension.

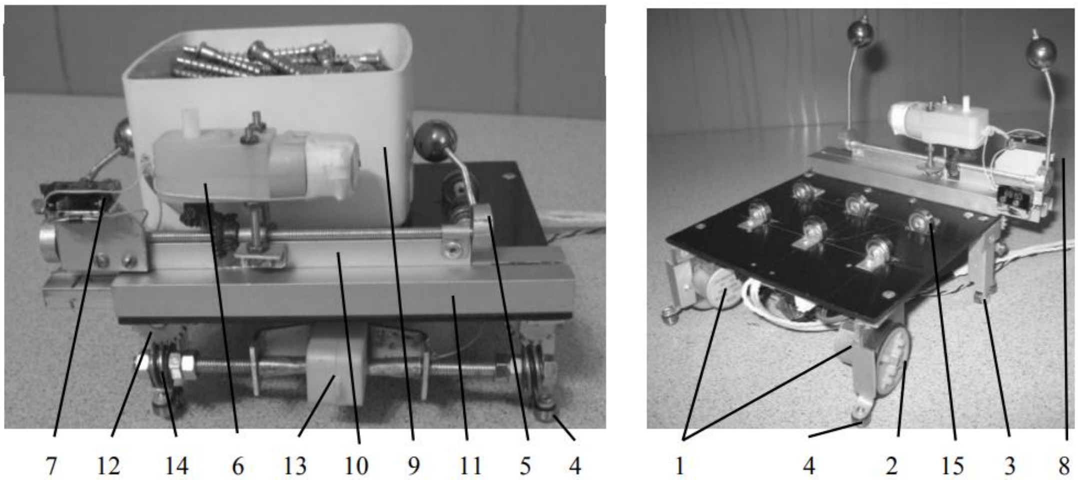

Fig. 3. The construction of the RMP experimental model

The unit for gripping and holding the container during its movement consists of a fork (5), which takes a horizontal and vertical position with the help of a servo motor with a gearbox (6). Fixation of the indicated positions is provided by limit switches (7) and mechanical limiters (8). In the horizontal position, the fork grabs and holds the container (9) when it is moved from the working surface of the RMP to the rack cell and from the rack cell to the working surface of the platform. In the vertical position, the fork releases the container in the rack cell.

The shift unit ensures the movement of the fork and the container to the right or to the left relative to the central axis of the RMP. Such movement is carried out with the help of a toothed rail (10), which moves to the right or to the left along the guides (11) with the help of two gears (12). These gears are rotated by a servo motor (13) and a worm gear (14). To fix the rail in two utmost positions and in the center of the platform, limit switches, mechanical limiters and an optosensor are used. To reduce the necessary shear force, the bottom of the container with two guides moves along two rows of bearings (three bearings in each row), which are placed on the working surfaces of the rack cells, elevators and robotic mobile platform (15).

To hold the container in the rack cell, the plane on which the bearings are placed is inclined downwards from the horizontal by an angle γ (Fig. 4). At the same time, the container rolls down to the stop which prevents it from falling out of the rack cell. The rolling force F_r is determined as follows

$$F_r = m_c \times g \times \sin(\gamma) \quad (1)$$

For the experimental model of the RMP with the mass of the loaded container m_c = 1.3 *kg* and the angle of inclination γ = 6.5°, the calculated value of F_r = 1.44 *N*. The experimentally measured value of F_e = 1.42 *N*. For the designed RMP with the mass of the container m_c = 40 *kg*, the calculated rolling force F_r = 44.34 N. This value determines the requirements to the shift unit of RMP.

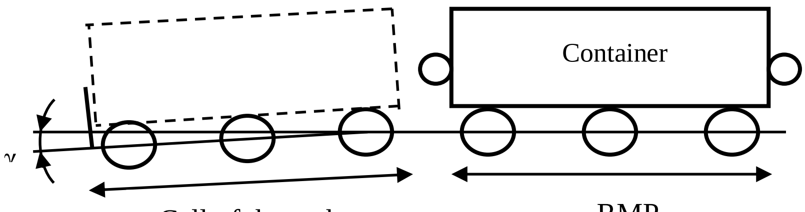

Fig. 4. Moving the container into the rack cell

One of the important tasks in the development of a drive unit for RMP is the selection of a drive stepper motor and its operating modes to ensure the movement of the platform with the required acceleration and speed. In addition, it must meet the weight and size requirements and ensure economical energy consumption.

The choice of a stepper motor, its parameters and operating mode is based on the force balance equation [8], [9]. With the same load m_w on the four wheels of the platform the modified force balance equation will be as follows

$$F_w = \mu \times m_w \times g \times \cos(\alpha) \quad (2)$$

$$F_s = m_w \times g \times \sin(\alpha) \quad (3)$$

$$2 \times M \times k/r = m \times a + 4 \times F_w + 4 \times F_s, \quad (4)$$

where: F_w – rolling friction force for wheel; μ - coefficient of resistance to movement [10] (taken equal to 0.03 *sm*); g – gravitation acceleration; α - permissible angle of the movement surface inclination (α = 1.5°); F_s - rolling force caused by the inclination of the movement surface; M – stepper motor torque (two drive motors are used); k – gear reduction ratio (k = 8); r – wheel radius (r = 3.75 *sm*); a – platform acceleration; m – total mass of the platform with container *(m = 50 kg, m_w = 12.5 kg)*.

From this equation, it is possible to determine the permissible acceleration of the mobile platform

$$a = (2 \times M \times k/r - 4 \times F_w - 4 \times F_s)/m \quad (5)$$

Taking into account the results of previous calculations, a stepper motor with a permanent magnet M49SP-2K was selected with the following parameters: Step Angle - 7.5 *°/step*, Rated Current/Phase -1 *A*, Max. Pull-out Pulse Rate – 1900 *pps* [11]. The nonlinear dependence of the torque of this motor on the pulse frequency [11], which is characteristic of most stepper motors, is presented in Fig. 5.

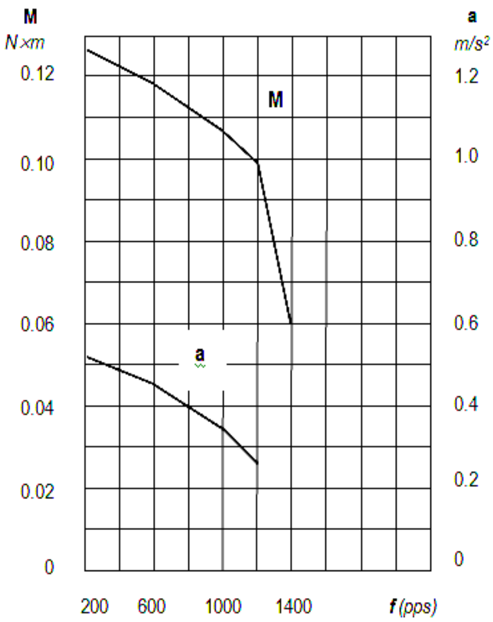

Fig. 5. Dependencies of torque and determined permissible acceleration on pulse frequency

The working frequency was chosen in the range of 200-1200 *pps*, because at lower frequencies resonant effects are manifested, and at higher frequencies the torque drops sharply. The dependence of *M (f)* in the selected frequency range can be approximated by three piecewise linear segments for frequencies 200-600 *pps*, 600-1000 *pps*, 1000-1200 *pps*. For the selected pulse frequency range, when using a single-stage gearbox with a gear ratio of 8:1 (k=8), the range of platform speeds from 0.123 to 0.736 *m/s* is ensured. After substituting the corresponding values in (5), the formula for determining the permissible acceleration will be:

$$a = 8.53 \times M - 0.55 \quad (6)$$

The calculated values of permissible acceleration and speed for the limiting frequencies of the sub-ranges are presented in the Tab. 1.

Table 1

The calculated values of acceleration and speed

f (pps)	*M (N×m)*	*a (m/s²)*	*v (m/s)*
200	0.125	0.516	0.123
600	0.118	0.457	0.368
1000	0.105	0.346	0,614
1200	0.100	0.303	0.746

Exceeding the determined permissible acceleration values leads to motor overload and skipping of steps. Therefore, it is proposed to use limitation of the value of platform acceleration/deceleration by changing the frequency and duration of pulses. In contrast to the approach presented in [12], where one given acceleration value is used, it is proposed to use three different acceleration values for the three frequency sub-ranges. The acceleration value calculated for the upper frequency of the sub-range is used.

The calculation of the duration of pulses τ_i carried out from the higher to the lower speed of the sub-range and starts from the third sub-range. In this case, the deceleration value is used *(d = – a)*. The array of τ_i values is determined using the following formulas

$$v_{i+1} = v_i + d \times \tau_i \,, \tag{7}$$

$$q = (v_i + v_{i+1}) \times \tau_i / 2 = v_i \times \tau_i + d \times \tau_i^2 / 2 \,, \tag{8}$$

$$\tau_i^2 + 2 \times v_i \times \tau_i / d - 2 \times q / d = 0 \,, \tag{9}$$

$$\tau_i = (-v_i + (v_i^2 + 2 \times q \times d)^{1/2}) / d \,, \tag{10}$$

where: q - is the distance traveled by the wheel in one motor step (q = 0.6136×10^{-3} *m*).

Conclusions

Delegating some functions to the containers storage system during the operations of loading/unloading and moving containers provided a significant simplification of the design and control system of the robotic mobile platform and increased its technical and economic indicators. Practical studies of the experimental model of the RMP confirmed the correctness of the design solutions. The obtained theoretical and practical results provide a basis for further design of a specialized RMP.

References

[1] M. Shneier and R. Bostelman, “Literature review of mobile robots for manufacturing”, NISTIR 8022, 2015, http://dx.doi.org/10.6028/ NIST.IR.8022.

[2] G. Cook and F. Zhang, “Mobile robots: navigation, control and sensing, surface robots and AUVs”, 2nd ed.,Wiley-IEEE Press, 2020.

[3] V. V. Mazur and S. T. Panchak, 2021, “Experimental model of a mobile platform for moving on orthogonal routes”, CAD in Machinery Design: Implementation and Educational Issues (CADMD 2020), IOP Conf. Series: Materials Science and Engineering, 1016 (2021) 012011 DOI: 10.1088/1757-899X/1016/1/012011, https://iopscience.iop.org/ article/10.1088/1757-899X/1016/1/012011/pdf

[4] M. A. Khan. “Design and control of a robotic system based on mobile robots and manipulator arms for picking in logistics warehouses”, Automatic, Normandie Université, English, 2020. NNT : 2020NORMLH31.

[5] V. V. Mazur, 2021, “Robotic mobile platform for container transportation”, IEEE 16th International Conference on Experience of Designing and Application of CAD System (CADSM 2021), pp. 10-13, https://doi.org/10.1109/CADSM52681.2021.9385212, https://ieeexplore.ieee.org/document/9385212

[6] https://www.kuka.com/en-de/products/amr-autonomous-mobile-robotics/mobile-robots/kmr-iiwa

[7] V. Mazur and S. Panchak, “Improvement of the construction and control system of the robotic mobile platform”, IEEE XXVIII International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory (DIPED), IEEE, 2023, pp. 242-246, DOI: 10.1109/DIPED59408.2023, https://ieeexplore.ieee.org/xpl/conhome/10269335/proceeding.

[8] T.A.T. Mohd and others, “Simulation based study of electric vehicle parameters”, ARPN Journal of Engineering and Applied Sciences, vol. 10, NO 19, 2015.

[9] V. Mazur and S. Panchak, “The research of the pecuiarities of the robotic mobile platform designing”, Proc. of the XXX Int. Polish-Ukrainian Conf. CAD in Machinery Design: Implementation and Educational Issues (CADMD 2022), Lviv, Ukrainian, 2022, p. 29.

[10] Kuchling H., Taschenbuch der Physik, Fachbuchverl. Leipzig im Carl-Hanser-Verlag, 2007.

[11] Stepping Motors M49SP-2K, https://www.mitsumi.co.jp/latest-M/Catalog/pdf/motor_m49sp_2k_e.pdf.

[12] V. Mazur and S. Panchak, “Control sysem for an experimental model of a robotic mobile platform with a manipulator”, Proc. of the XXIX Int. Polish-Ukrainian Conf. CAD in Machinery Design: Implementation and Educational Issues (CADMD 2021), Ukrainian, Lviv, 2021, p. 15.

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РОБОТИЗОВАНА МОБІЛЬНА ПЛАТФОРМА ДЛЯ СИСТЕМИ ЗБЕРІГАННЯ КОНТЕЙНЕРІВ

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Анотація. Невиправдана концентрація інтелектуальних функцій управління та засобів вантажно-розвантажувальних робіт і переміщення контейнерів погіршує техніко-економічні показники антропоморфних роботизованих мобільних платформ класу AMR (Autonomous Mobile Robot). У роботі запропоновано перспективний підхід, який базується на комплексній розробці автоматизованої системи зберігання контейнерів та спеціалізованої роботизованої мобільної платформи для врахування особливостей та підвищення ефективності їх спільної роботи. У роботі розглянуто запропоновану структуру та організацію автоматизованої системи зберігання контейнерів. Для ефективного функціонування цієї системи розроблено спеціалізовану роботизовану мобільну платформу. Представлена експериментальна модель роботизованої мобільної платформи для дослідження особливостей реалізації її вузлів і системи керування. Запропоновано рішення щодо забезпечення точності позиціонування платформи та контейнера під час їх руху.

Ключові слова: система зберігання контейнерів, роботизована мобільна платформа, експериментальна модель, точність позиціонування.