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MODERNIZATION OF THE WORK CONTROL SYSTEM BY THE PUMA-560 MANIPULATOR

Abstract. Modern production is impossible without the introduction of advanced technologies, which are reflected in the concept of the fourth industrial revolution Industry 4.0. The proposed concept affects all areas of production processes, through the introduction of cyber-physical production systems (CPPS), robotic systems (RS), artificial intelligence (AI), the use of Industrial Internet of Things (IIoT) and the desire for full automation of all technological processes (TP). This approach to the implementation of production processes allows to solve a number of complex problems: optimization and automation of TP, obtaining data on the implementation of TP in real time, collecting analytical information for monitoring and forecasting, which will allow to fulfill the requirements of Lean Manufacturing (LM). To solve these problems, it is necessary to create a single information environment, based on IIoT, which would cover all stages of production management.

This requires that all equipment be part of a single information space of the enterprise, for which it is necessary to replace obsolete equipment with new one with the support of digital control systems, which leads to large financial losses. In this regard, many companies are considering the task of upgrading existing equipment. The solution of this problem is a complex scientific and technical problem, the solution of which covers the following areas: the theory of automatic control, circuitry, programming. One of the difficult objects to upgrade is a robot manipulator.

This article discusses some aspects of solving the problem of modernization of the robot control system manipulator PUMA-560 (PM-01). The study of actuators, PM-01 engines and control cabinet Puma Mark III (Sphere-36 (56)), developed a structural control scheme PUMA-560 lower level. The element base is analyzed, the microprocessor is chosen and the circuit diagram is designed. Using EDA Altium Designer, a printed circuit board for the PUMA-560 manipulator control system was developed with the ability to connect to modern microcomputers, such as LattePanda, running Windows 10/11. The proposed solution, according to the authors, will automate the control system of the manipulator PUMA-560 and connect it to a single information network based on IIoT.

Keywords: Industry 4.0, module, control system, industrial robot, manipulator, modernization, CAD EDA.

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МОДЕРНІЗАЦІЯ СИСТЕМИ КЕРУВАННЯ РОБОТОМ МАНІПУЛЯТОРОМ PUMA-560

Анотація. Сучасне виробництво неможливе без впровадження передових технологій, які відображені в концепції четвертої промислової революції Industry 4.0. Запропонована концепція зачіпає всі сфери виробничих процесів, за рахунок впровадження кібер-фізичних виробничих систем (КФВС), робототехнічних систем (РС), систем штучного інтелекту (ШІ), використання Industrial Internet of Things (IIoT) і прагнення до повної автоматизації всіх технологічних процесів (ТП). Даний підхід реалізації виробничих процесів дозволяє вирішити ряд складних завдань: оптимізації і автоматизації ТП, отримання даних про виконання ТП в режимі реального часу, збір аналітичної інформації для моніторингу і прогнозування, що дозволить реалізувати вимоги Lean Manufacturing (LM). Для вирішення даних задач необхідним є створення єдиного інформаційного екосередовища, на основі IIoT, яке б охоплювало усі етапи управління виробництвом.

Для цього необхідно щоб все обладнання було складовим єдиного інформаційного простору підприємства, для чого необхідно проводити заміну застарілого обладнання на нове з підтримкою цифрових систем управління, що призводить до великих фінансових втрат. У зв'язку з цим багато підприємств розглядають задачу модернізації існуючого обладнання. Рішення даного завдання є складною науково-технічною проблемою, вирішення якої охоплює такі напрямки: теорія автоматичного управління, схемотехніка, програмування. Одним із складних об'єктів для модернізації, є робот маніпулятор.

У даній статті розглянуті деякі аспекти вирішення завдання модернізації системи управління роботом маніпулятором PUMA-560 (РМ-01). Проведено дослідження виконавчих механізмів, двигунів РМ-01 і шафи управління Puma Mark III (Сфера-36 (56)), розроблено структурну схему управління PUMA-560 нижнього рівня. Проаналізовано елементну базу, обраний мікропроцесор і спроектована схема електрична принципова. Використовуючи EDA Altium Designer була розроблена друкована плата системи управління маніпулятором PUMA-560 з можливістю підключення до сучасних мікрокомп'ютерів, типу LattePanda, під керуванням OS Windows 10/11. Запропоноване рішення, на думку авторів, дозволить автоматизувати систему управління маніпулятором PUMA-560 і підключити його в єдину інформаційну мережу на базі IIoT.

Ключові слова: Індустрія 4.0, модуль, система управління, промисловий робот, маніпулятор, модернізація, CAD EDA

Formulation of the problem. Smart Manufacturing – these are fully integrated corporate production systems that are able to respond in real time to changing production conditions [1-3]. This can be achieved through the intensive and comprehensive use of modern information technology and CPPS [4, 5]. The complexity of the implementation of CPPS is the need to implement a cross-cutting information space, through the use of IIoT. Therefore, it is necessary to buy new equipment, put it into operation, it is very expensive and often not economically viable. Therefore, many companies, including in Ukraine, prefer to modernize equipment. Modernization of industrial equipment is a complex scientific and technical problem that combines the solution of many problems, such as: scientific research and analysis; research and design; development and implementation of control systems for complex mechanisms, which is a robot manipulator PUMA-560.

In this case, during operation, the Puma Mark III control cabinet (Sphere-36 (56)) PUMA-560 manipulator failed. Searching for solutions for the repair of the control cabinet, it was found that it will be expensive due to the cost of spare modules, and the control system will not meet modern requirements for Smart Manufacturing. Based on this, the authors were tasked to modernize the operation of the manipulator PUMA-560, which will provide the ability to remotely control and monitor, using IIoT technologies.

Analysis of recent research and publications. [6] shows the approach of modernization of the PUMA-560 manipulator, due to the use of I / O board Humusoft MF634, which provides data collection. This solution enabled Matlab Real-Time Windows Toolbox support for real-time applications. The authors [6] control system of the robot manipulator PUMA-560 was developed in the Matlab environment, this solution is convenient for use as laboratory stands. The authors [7] in their studies simulated the operation of the manipulator PUMA-560 through the use of PIC microcontrollers for each control unit. The authors [8] developed an adaptive projection neural network (PNN) with online learning to solve the problem of manipulator control, conducted theoretical and software modeling.

The analysis showed that the proposed solutions for the modification of the control system of the robot manipulator PUMA-560, can be used in laboratory and research work, and they can not be used in a real production process.

The purpose of the article – research and modernization of the drive control system of the RM-01 manipulator.

Presenting main material. Programmable Universal Manipulation Arm (PUMA) – an industrial robot manipulator developed by Victor Scheinman of Unimation for General Motors. General view of the control cabinet

Puma Mark III (Sphere-36 (56)) and the operation of the manipulator PUMA-560 are presented in fig. 1 and fig. 2.

Fig. 1. *General view of the control cabinet Puma Mark III (Sphere-36 (56))*

Fig. 2. *General view of the PUMA-560 manipulator*

This is a six-link industrial manipulator capable of moving equipment to any point of the work area. The links of the manipulator are connected to each other by means of rotary hinges ("joints"), which rotate around the axes of the coordinate systems that go through the centers of the joints (Fig. 3). Swivel hinges are equipped with tracking drives.

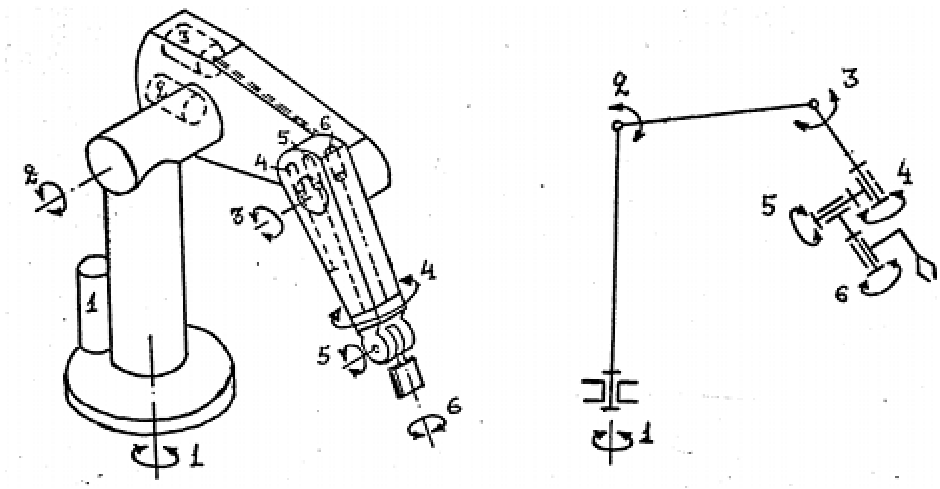


Fig. 3. *Swivel joints work PUMA-56 and its kinematic scheme*

The following electric drive is a closed system with rigid position feedback. This connection is possible thanks to encoders - electromechanical devices, which determine the position of rotation around the axis. Mechanical motion is converted into electrical signals that determine the position of the object and provide information about the angle of rotation of the shaft, its position and direction of rotation. The following electric drive operation of the PUMA-560 manipulator is presented in figure 4. Figure 4 a shows the following electric drive with the encoder of the first pivot joint, and Figure 4 b for the third joint.

a) b)

Fig. 4. *The following electric drive works of the PUMA-560 manipulator*

The manipulator has six pairs of links of the fifth class which includes six motors of a direct current of independent excitation (DPS-NZ) from permanent magnets which maximum supply voltage is 42 V, and current to 10 A. The rotation of the links is carried out around the axes passing through the centers of the joints. Each link has a DC servo with excitation from permanent magnets, potentiometric and optical-pulse position sensors, gears, electromagnetic brakes (EMB). The EMB must be switched off by a separate signal when moving the link. The brakes are activated when the supply voltage of the motors is turned off, while the manipulator is locked in the position in which it was at the time of power off.

To simplify the development of the control system of the robot manipulator PUMA-56, it was decided to design a generalized block diagram, which is presented in fig. 5.

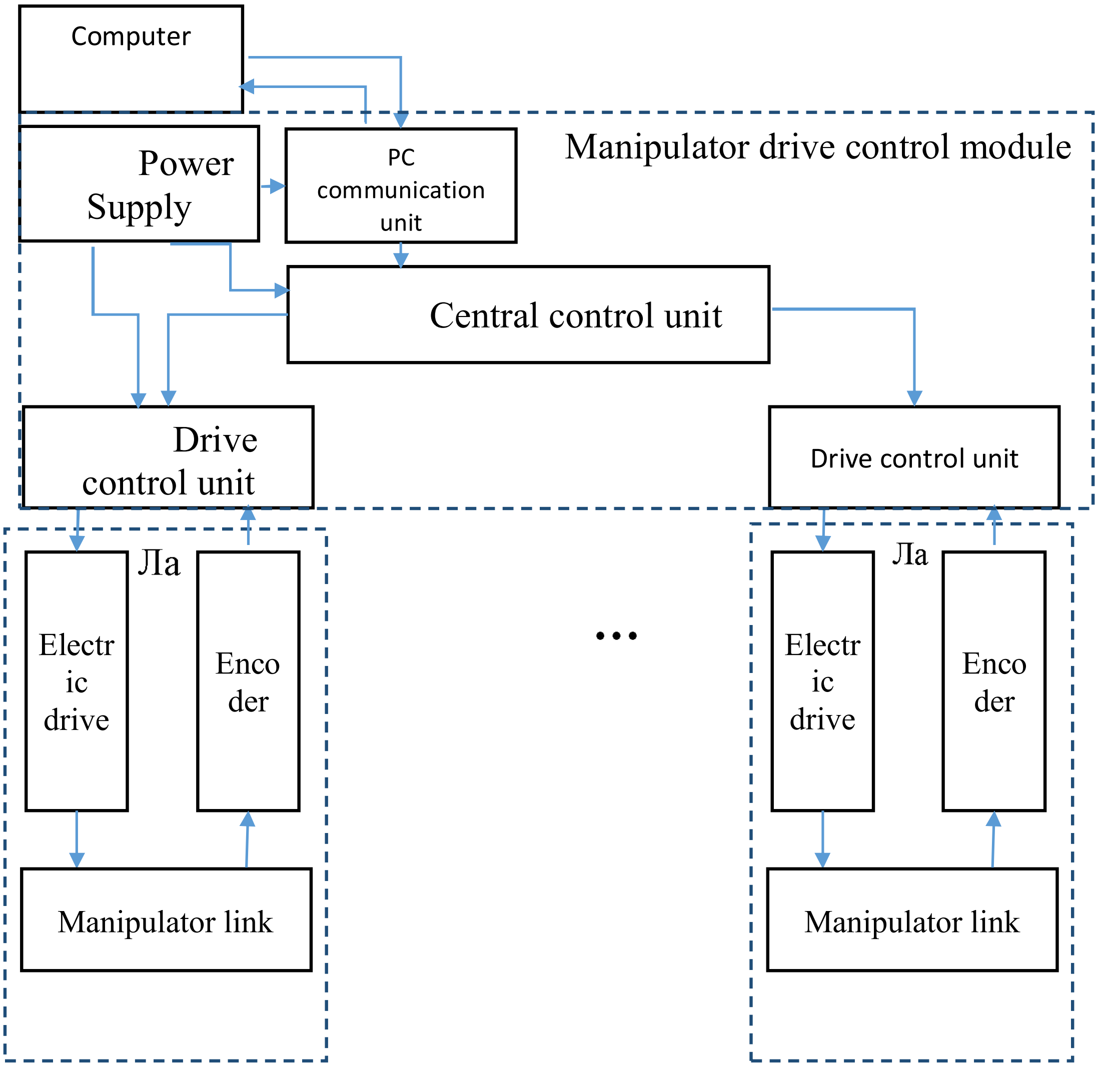


Fig. 5. *Generalized structural diagram of the module*

The central part of the given structural scheme is the single-chip microcontroller under which management all basic functions of the device are realized. The power supply must be disconnected to ensure that no current can be applied to the load. We will build control of the separate drive on the basis of ATMEGA328. This is an 8-bit CMOS microcontroller with low power consumption, built on an advanced AVR RISC architecture [9].

The connection diagram shown in fig. 6 contains: connectors for connecting the encoder, motor, power supply; controls (button); stabilizer; quartz oscillator and necessary matching electroradioelements (ERE). We use the standard scheme of connection of chips, providing for each separate power supply, to ensure the impossibility of mutual influence on the current when applying the load.

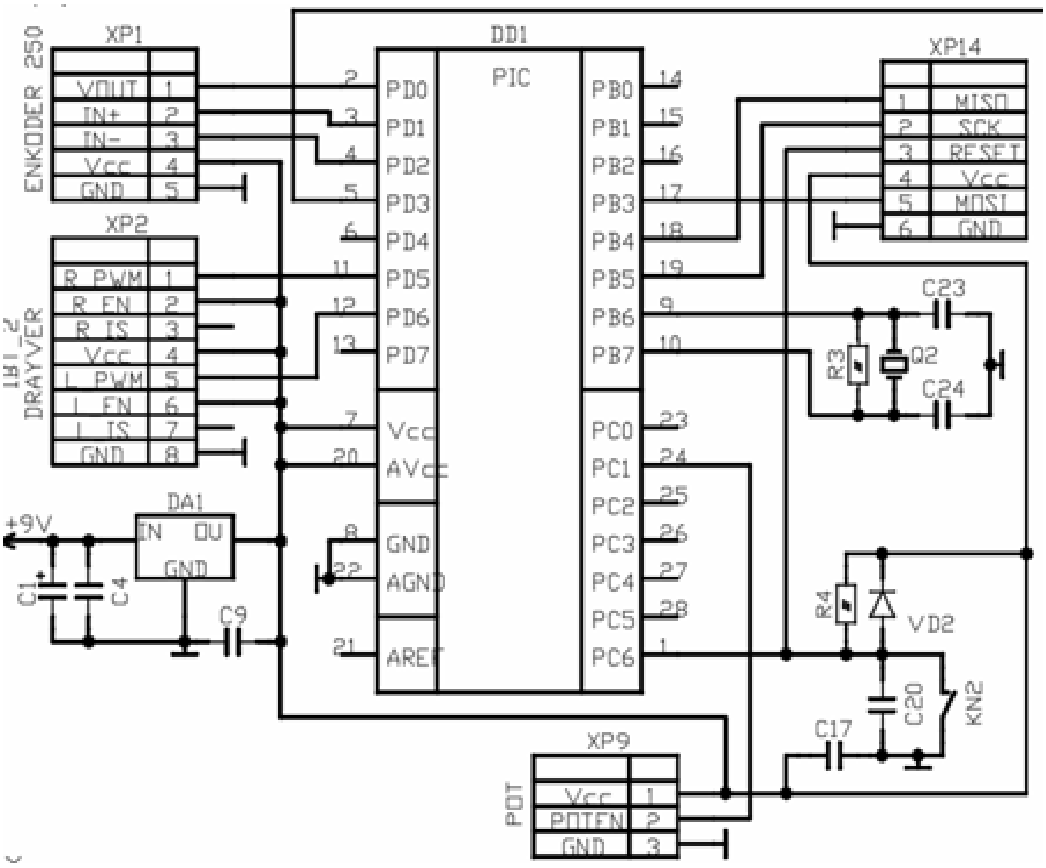


Fig. 5. *Schematic of the electrical principal module control of one drive*

To control the six-coordinate manipulator RM-01 requires six such modules for each drive. For communication of modules and information processing with control units we use ATMEGA2560 and ATMEGA16U2 for communication with the personal computer [10, 11]. We provide connectors for in-circuit programming and connection of sensors and motor drivers. The circuit diagram of the basic control module of the robot manipulator PUMA-56 is presented in fig. 6. Each single drive control module is connected via terminal 5 (PD3) to the PG0 – PG5 (1,28,29,51,52,70) pins on the ATMEGA2560. During the development of the electrical circuit diagram, the authors proposed the following modifications (fig.6):

- XP28 connector allows you to connect a keyboard to test the angles of rotation of DC motors;
- XP27 and XP34 connectors allow you to connect additional modules via Serial Peripheral Interface (SPI);
- XP32 connector allows you to connect any USB device;
- the XP33 connector connects to a 9V power supply;
- the XP22 connector connects the Nokia 5110 monochrome graphic display.

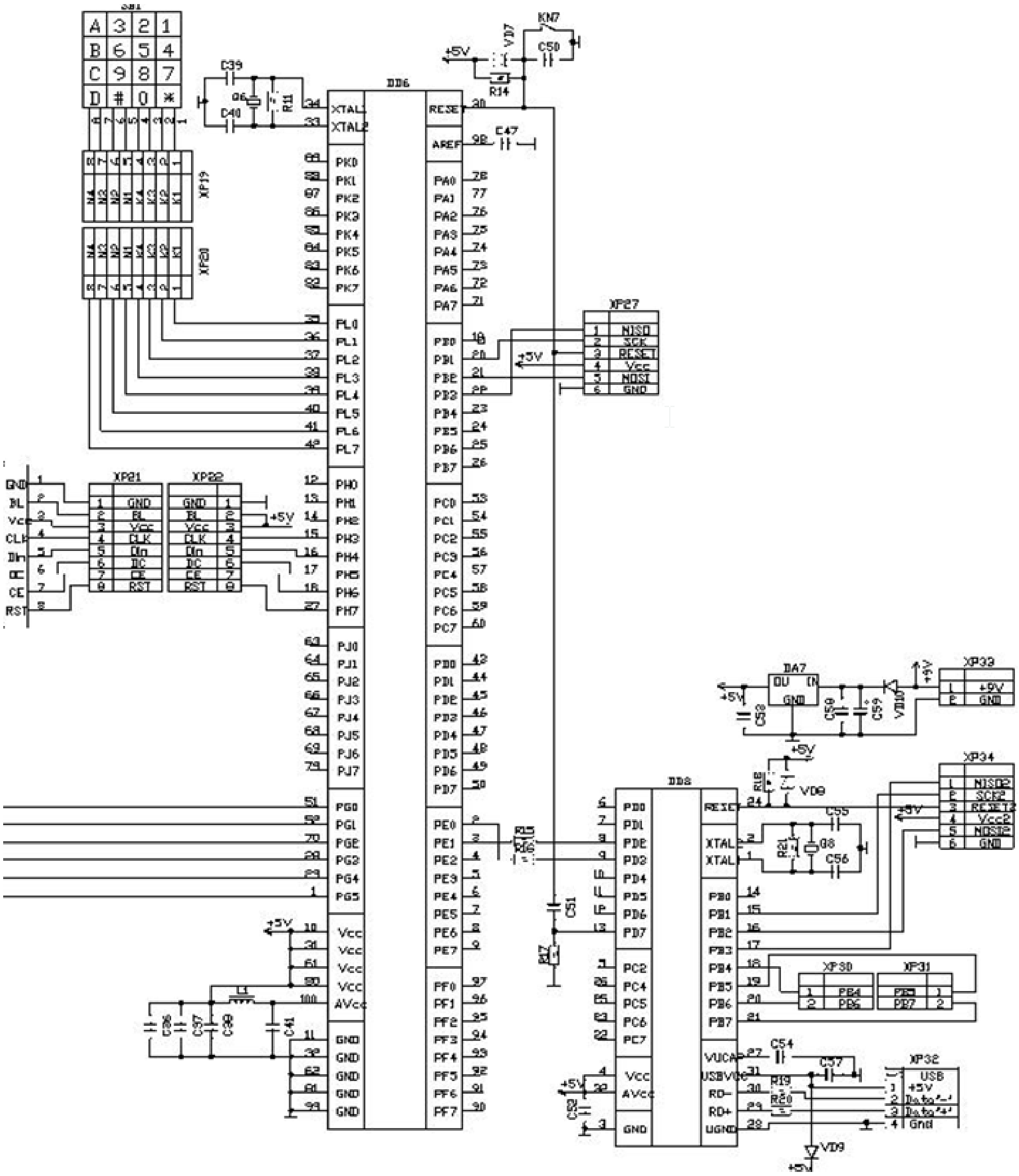


Fig. 6. *Schematic diagram of the basic control module of the PUMA-56 robot manipulator*

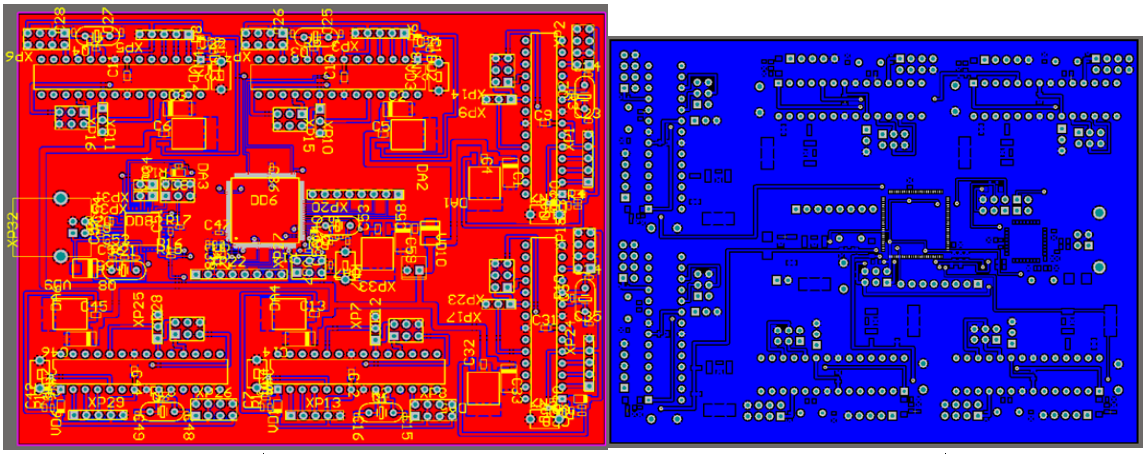
Based on the developed circuit diagram of the electrical control module of the robot manipulator PUMA-56, it is necessary to design a printed circuit board (PCB). During the analysis it was suggested to use the following element base:

- ATmega2560-16AU (DD6) – microcontroller based on AVR-core with RISC-architecture. The AVR core has a set of instructions with 32 general-purpose working registers;

- 78xx series chips (LM78xx) – family of linear integrated voltage regulators [11]. Due to the ease of use and low cost, the chips of this series have found use in electronic circuits that require a stabilized power supply. The chip has built-in overheat protection and one-slope protection of the output transistor from overload;

- passive elements are selected in SMD execution;
- for reprogramming the board USB connector PN61729 [12];
- PLS connectors are used to connect the keyboard and switch individual modules.

Engineers also performed calculations of mass and dimensional parameters of the module, the area of the printed circuit board, the width of the printed conductor and the calculation of the overall dimensions of the module. The next step is to design a PCB. For this purpose the complex system of the automated designing of radio electronic means Altium Designer is chosen [13]. During the design, a database of electronic components (Schematic Library and PCB Library) was developed and the layout of the selected components was made with the subsequent tracing of the PCB. Figure 7, a shows the result of tracing the layer "Top", and 7, b the result of tracing the layer "Bottom" of the robot control module manipulator PUMA-56 in Altium Designer.



а) б)

a) the result of tracing the layer "Top"; b) Bottom layer trace result

Figure 7 - The result of tracing the robot control module manipulator PUMA-56 in Altium Designer

The obtained results of tracing the robot control module manipulator PUMA-56 in Altium Designer were sent in the form of Gerber-file, for production in PCBWay [14]. PCB material was selected FR-4 with a thickness of 1.6 mm, the minimum thickness of the tracks 6/6 mil, the minimum hole diameter 0.8mm.

Conclusions. In the course of research on solving the problem of modernization of the control system of the robot manipulator PUMA-56 for use in IIoT networks, an analysis of the following electric drives, parameters and features of their designs. The generalized block diagram of the control module of a six-link design for management of each joint separately based on ATMEGA328 is offered that allowed to implement the combined management. On the basis of the generalized control structure of the robot manipulator PUMA-56 and modern CAD EDA Altium Designer the scheme of the electric basic module of control of the robot manipulator PUMA-56 on the basis of the ATmega2560-16AU microcontroller is developed and the printed circuit board is designed. For the developed printed circuit board of the PUMA-56 robot control module, the authors obtained a Gerber file and proposed parameters for its production on PCBWay. In the future, the authors plan to install and solder the components of the robot control module manipulator PUMA-56 and conduct experimental studies on control, movement accuracy and stability.

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