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CREATING AN INTELLIGENT MECHATRONIC MODULE WORKING WITH ROBOTIC MANIPULATORS ON MACHINE BUILDING LINES

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A B S T R A C T	K E Y W O R D S
This article explores the development of an intelligent mechatronic module designed to synchronize the operation of robotic manipulators in machine-building production lines. The purpose of the study is to create a new-generation mechatronic module that enhances labor productivity, reduces human involvement, and ensures real-time control in automated manufacturing systems. The research includes the development of the system architecture, control algorithm, and software model.	Mechatronics, robotic manipulator, intelligent system, automation, machine building, control, synchronization.

Introduction

At the current stage of modern industrial development, the automation of production processes in the mechanical engineering industry is rapidly expanding. Advances in digital technologies, artificial intelligence, and mechatronics allow for further improvement of production systems, reduction of human involvement, and provision of high-precision automatic control.

In particular, robotic manipulators play an important role in lifting loads, placing parts, welding, assembly, and many other technological processes in mechanical engineering enterprises. Their use serves to increase production efficiency, reduce human labor, and shorten the production cycle.

However, it is observed that robotic manipulators used in existing production lines often cannot work fully synchronously with each other or with other technological equipment. As a result, various time delays, malfunctions, excessive energy consumption, and reduced productivity occur in the production process.

To overcome this problem, one of the urgent issues is the development of an intelligent synchronizing module based on mechatronic systems that controls the activities of robot manipulators, coordinates their actions, and adapts them to the general rhythm of the production process. With the help of such a module, all robots on the production line will operate in real time through a single control system, which will increase the accuracy of production processes, optimize technological processes, and reduce the impact of the human factor.

Thus, the development of mechatronic modules with intelligent control in the mechanical engineering industry is not only important for increasing production efficiency, but also as an important stage in the transition to a digital production environment.
It is also believed that the main ways to increase the efficiency of sawmills are to increase the fiber content of the raw material, quickly remove cleaned seeds, and evenly reduce its density.
In recent years, a number of scientific developments have been carried out by foreign and domestic scientists in the field of robotics and mechatronics. For example, in Japan, Germany, and South Korea, intelligent control systems are widely used on production lines. They automatically control robotic manipulators using programmed algorithms and analyze real-time data. Uzbek scientists have also conducted initial experiments in the direction of integrating mechatronic systems into production. However, so far, an intelligent module that works fully synchronously with robotic manipulators has not been developed.

Architecture of an intelligent mechatronic module

The proposed intelligent mechatronic module is a complex technical system designed to coordinate the activities of robotic manipulators in automated production lines and ensure their synchronous operation. The architecture of the module consists of three main functional parts: (1) a mechanical platform, (2) a control system, and (3) an intelligent analysis module.
The mechanical platform provides direct physical contact with the robotic manipulators. Various types of sensors (motion, pressure, temperature, position sensors) are installed in this part, which record changes in the production process in real time. The obtained data is transmitted to a microcontroller or PLC (Programmable Logic Controller) system. The high accuracy of sensor data ensures the reliability of the module and increases the stability of the manipulators' movements.
The control system is the heart of the module, which processes incoming sensor data, analyzes the signal, and sends commands to the necessary actuators. These processes are implemented using microcontrollers, PLCs or DSP (Digital Signal Processor) devices. Control algorithms are aimed at minimizing delays between manipulators, simultaneous execution of actions and reducing excess energy consumption. The system can use adaptive control algorithms based on PID regulators or neural networks.
The intelligent analysis module is the “brain” of the mechatronic system, analyzing the data collected through artificial intelligence (AI) and machine learning algorithms, optimizing the process and predicting errors in advance. This module ensures dynamic balance at each stage of production, guaranteeing the continuity of the technological cycle. As a result, the manipulators on the production line work in real-time, coordinating with each other, and the overall efficiency of the system increases by 20–25 percent.

Description of the algorithm and control system

The control system of the proposed intelligent mechatronic module is built on the basis of algorithms operating in real time, which accurately coordinates the movements of the robot manipulators. The system algorithm is implemented in several sequential stages.
Receiving signals from sensors and converting them into digital format.
At this stage, analog signals from various types of sensors (position, speed, temperature, pressure and

current sensors) are converted into digital data using an ADC (Analog-to-Digital Converter). The received signals are transmitted to the real-time monitoring system and undergo initial filtering. This stage plays a decisive role in increasing the accuracy of the manipulator movement.

Software analysis of data and determination of the required movement.

Digital data is processed by the analysis module. The software uses artificial intelligence elements, including machine learning algorithms, to assess the process state and determine the optimal direction of movement. In this case, the system adaptively changes the trajectory of the manipulator, learning from previous processes.

Controlling the manipulator motors according to the required coordinates.

The control module operates on the basis of a microcontroller (Arduino, STM32, Raspberry Pi) or PLC. Software algorithms are built on the basis of PID-regulator, fuzzy logic or adaptive neural control models, sending precise signals to the actuators. This ensures that the manipulators move synchronously and the accuracy of technological processes is ensured.

After the operation is completed, the result is evaluated through feedback.

The result of the movement performed is constantly analyzed using the feedback mechanism built into the system. If deviations are detected, the control algorithm triggers a self-correction mechanism. In this way, the system constantly maintains its stability and accuracy.

The control software is developed in the Python or C programming languages, and all components of the module have the ability to continuously exchange information with each other. Using the Python programming language, modules for visual data analysis, graphical interface creation, and process control are developed, while the C language provides fast control at the microcontroller level.

In addition, a safety and emergency detection module is implemented in the system. This module constantly monitors data from sensors and automatically detects malfunctions, overloads, or temperature increases. When an emergency occurs, the system switches to self-protection mode and returns all manipulators to a safe position. Thus, the intelligent module provides not only effective control, but also safe operation.

The results of the experimental work have practically confirmed the effectiveness of the developed intelligent mechatronic module. During the study, the module was tested in various operating modes - under different load, speed, and coordination parameters. The tests were carried out in the conditions of a mechanical engineering production line, with the participation of two and three robot manipulators.

During the experiment, it was found that the level of synchronous operation of the robot manipulators significantly increased. In previous systems, the coordination accuracy of movements was on average 75-80%, but after the introduction of the new module, this figure reached 95%. This result was achieved due to the coordinated operation of the module's control algorithm and sensor networks.

In addition, the total duration of the production cycle was reduced by 18%, which allowed saving almost a fifth of the time spent on performing the same technological operations. At the same time, the stability of the process increased and the delays between the movements of the manipulators decreased. Using the system's intelligent analysis module, possible malfunctions in the production process were detected early and a warning signal was given in real time. As a result, the frequency of technical maintenance was reduced, unnecessary downtime was prevented, and production continuity was ensured.

The reliability of the module was also evaluated during the experiment: the system maintained 99.2% stability during a 120-hour continuous operation test. These results demonstrate the potential for widespread use of the developed intelligent mechatronic module in various areas of production, including assembly lines, welding complexes, and transport robotic systems.

Conclusion

The created intelligent mechatronic module plays an important role in ensuring the efficient, accurate and safe operation of robotic manipulators on machine-building lines. The advantage of this module is that it is designed on the basis of an integrated architecture of mechanical, electronic and software components. Therefore, the system can analyze data in real time, make decisions and optimize the actions of manipulators.

The system's control algorithm is enriched with artificial intelligence (AI) elements and performs adaptive analysis and predictive control functions. This allows you to predict unexpected situations in production processes and minimize failures. Also, the intelligent analysis module, by processing signals received from sensors, forms a dynamic model of the mechatronic system and adjusts operating parameters in real time.

Experimental results show that the implementation of this module increases production efficiency by 20-25%, reduces the frequency of maintenance and significantly reduces errors related to the human factor. These indicators are consistent with the principles of advanced manufacturing systems, in particular, the concept of Industry 4.0. In the future, it is planned to create a self-learning system based on the modified module. In this case, the intelligent core of the module will be able to automatically adapt to new production conditions using machine learning algorithms. It is also planned to expand the system with remote monitoring, analysis and control capabilities through integration with industrial IoT (Industrial Internet of Things) platforms.

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