Development of Scientific and Educational System: European Vector – 2024

**Series of monographs
Slovak Publishing House
NES Nová Dubnica s.r.o.
Monograph 2**

Publishing House NES Nová Dubnica s.r.o., 2024

Series of monographs Slovak Publishing House NES Nová Dubnica s.r.o., Slovenská Republika

Monograph 2

ISBN 988 – 963 – 8454 – 15 – 6 - 6S

Editorial compilation
Publishing House NES Nová Dubnica s.r.o.
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CHAPTER 4. TRAINING OF SPECIALISTS IN MODELING, PROGRAMMING AND CONTROL OF MECHATRONIC COMPLEXES

4.1. Fundamentals of Mechatronic Complexes and Training of Specialists in the Field of Mechatronics Today

Mechatronic systems consist of three main components:

1. Mechanical components: these are various mechanisms, motors and gearboxes that perform physical work. For example, in industrial robots, mechanical arms perform manipulations with objects.

2. Electronics: these are controllers, sensors and other electronic elements that provide data processing and control of mechanisms. They are responsible for obtaining information from the environment and making decisions based on this data.

3. Software: these are algorithms that implement management strategies and data processing. Programming ensures the integration of mechanical and electronic components into a single system [1–10].

Let's consider each component of mechatronic systems in more detail:

1. Mechanical components. Mechanical elements are the basis of mechatronic systems. They provide the physical structure and functionality, performing mechanical work. The main mechanical components include:

– motors – used to convert electrical energy into mechanical energy. They can be of different types: direct current, alternating current, stepper and servo motors. Each type has its own advantages depending on the requirements for accuracy, speed and power;

– reducers – reduce the speed of rotation of motors, increasing the torque. They are necessary for optimizing the operation of mechanical systems, in particular in works that require high positioning accuracy;

– sensors – measure physical quantities (temperature, pressure, humidity, position, speed, etc.) and transmit this data for processing. For example, optical sensors can be used to determine position or distance;

– actuators – perform physical actions based on commands received from the controller. They can be electrical, hydraulic or pneumatic;

– structural elements – include gears, shafts, bearings, frames and other mechanical parts that ensure the structural integrity and functionality of the system.

Functions and importance of mechanical components: mechanical components ensure the performance of the main functions of mechatronic systems. They allow the conversion of electrical energy into mechanical work, provide accuracy and control over movements, as well as interaction with the environment. Without reliable mechanical elements, the system will not be able to operate efficiently and safely.

2. Electronic components. Electronics are the heart of mechatronic systems, providing information processing and control of components. The main electronic components include:

– microcontrollers – these devices are the "brains" of mechatronic systems, they process data from sensors and give commands to actuators. Popular microcontrollers, such as Arduino, PIC and STM32, are widely used in education and development;

– sensors – include a variety of devices that can measure various physical quantities. For example, accelerometers measure acceleration, and temperature sensors – temperature. This data allows the system to respond to changes in the environment;

– analog and digital circuits – are used for signal processing, voltage changes, filtering and signal amplification. These elements are necessary to ensure the correct operation of sensors and actuators;

– power supplies – provide stable power supply for the entire system, converting voltage and providing the necessary current for all components.

Functions and importance of electronic components: Electronics provide intelligence to mechatronic systems, allowing them to collect data, analyze information and make decisions. Thanks to electronic components, systems can respond to changes in the environment and execute complex control algorithms. This makes them extremely flexible and adaptive.

3. Software. Software is a critical element responsible for the logic of mechatronic systems. It includes:

– operating systems – provide a basic platform for the programs that control the system. Embedded systems often use lightweight versions of Linux or RTOS (Real-Time Operating System);

– control algorithms – include mathematical models and methods that determine how the system responds to input data. This can be simple control (PID controllers) or complex algorithms that use machine learning;

– user interfaces – allow operators to interact with the system. This can be a graphical interface, web applications or mobile applications;

– data acquisition and analysis systems – software may include tools for collecting, storing and analyzing data received from sensors [11-20].

Functions and importance of software: software is what gives mechatronic systems their “intelligence”. It converts data received from sensors into control commands for actuators. Without appropriate software, mechanical and electronic components will not be able to work harmoniously, which will lead to system failures.

It is also necessary to consider specific examples of mechatronic complexes in various industries, because it is mechatronic complexes that are widely used in various fields, from industry to medicine. Here are some specific examples that illustrate the diversity of their use:

1. Medicine: Surgical robots – da Vinci (da Vinci Surgical System) – the da Vinci surgical system is one of the most famous examples of mechatronics in medicine. It consists of three main components: the surgeon’s workstation, the patient module and the video system. The surgeon sits at a console that has controllers to control the instruments. The system transmits the surgeon’s movements to robotic instruments that operate with high precision. Video cameras provide real-time 3D images, allowing the doctor to see the surgical field in high detail. This allows complex surgeries to be

performed with minimal incisions, reducing the risk of complications and the recovery time of patients.

2. Industry: Robotic Systems – Collaborative Robots – Cobots, or collaborative robots, are integrated into production lines and work alongside people. They are equipped with sensors that allow them to safely interact with people. They perform routine tasks such as assembly, packaging and quality control of products. They can adapt to changes in the production process thanks to built-in learning algorithms. The use of cobots increases productivity, reduces the risk of injuries to workers and allows tasks to be performed with high precision.

3. Automotive Industry: Autonomous Vehicles – Tesla Autopilot – the autopilot system in Tesla cars is one example of the use of mechatronics in automotive transport. It combines mechanical elements, electronics and software. The system uses cameras, radar sensors and ultrasonic sensors to collect information about the environment. It is able to automatically change lanes, control speed and even park without driver intervention. This opens up new horizons for road safety, reduces accidents and increases driving comfort.

4. Agriculture: Harvesting robots – Agro-robots – the use of robots in agriculture for harvesting crops, such as berry or vegetable harvesting robots. These robots are equipped with sensors that help determine the ripeness of fruits. They can precisely harvest without damaging plants and fruits. They reduce the need for manual labor, increase harvesting efficiency and reduce costs.

5. Home technologies: Smart home devices – Smart vacuum cleaners (e.g. Roomba) – robot vacuum cleaners use mechatronics to automate the cleaning process. Equipped with sensors for navigation, they are able to detect obstacles, identify contaminated areas and adapt their cleaning trajectory. They reduce the burden on humans by providing the ability to automate everyday tasks [37–40].

Mechatronic systems are being actively implemented in various fields, improving efficiency, safety and convenience. From surgical robots to smart home devices, these technologies are changing the way we live and work, which emphasizes the importance of training specialists in this dynamic and innovative field.

It is the successful integration of mechanical, electronic and software components that is the key to the effectiveness of mechatronic systems. Each of these elements performs unique functions that interact with each other, providing a high level of automation and control. Training specialists who can design and implement these systems is critically important for the development of modern technologies and in the training of future specialists in modeling, programming and controlling mechatronic systems.

Training specialists in the field of mechatronics is a complex and multifaceted process that requires a combination of theoretical knowledge and practical skills, as well as an integrated approach. The main aspects that should be considered:

– Technical subjects: students should study mathematics, physics, engineering mechanics, electrical engineering and programming. These subjects form the basis for understanding the principles of mechatronic systems. In particular, mathematics allows you to model physical processes, while physics provides knowledge about the laws of motion and force.

– Practical skills: it is important that students have the opportunity to work with real projects, using modern tools and software. Laboratory work, internships in industry, participation in competitions and project work help to gain practical experience.

– Interdisciplinary approach: mechatronics requires knowledge from different fields. Therefore, it is important that curricula ensure the integration of subjects such as automation, robotics and computer science.

Let's take a look at the curricula: what subjects are studied; what skills are developed.

Having analyzed the curricula, we can say that different countries have different approaches to training specialists. For example, in the USA, the emphasis is on practical aspects of training, while in Europe more attention is paid to theoretical foundations. Countries that successfully implement mechatronics programs often provide students with access to modern laboratories and research projects.

The training of mechatronics specialists varies significantly depending on the country, university and education system. Let's consider several countries that have strong programs in this field and compare their curricula, emphases and approaches.

1. Germany – is one of the leaders in the field of mechatronics due to its strong engineering tradition. Programs are usually interdisciplinary, combining mechanics, electronics, computer science and automation. Focused on practical training and cooperation with industry. Examples of universities: Technical University of Munich (TUM) and Technical University of Dresden. Specificity: strong emphasis on practical laboratory classes and projects in collaboration with industry; students undergo internships at leading companies.

2. United States of America – Mechatronics is often studied as part of broader engineering programs (e.g. mechanical, electrical or computer engineering). Programs cover a variety of disciplines such as robotics, automation and control systems. Examples of universities: Massachusetts Institute of Technology (MIT) and University of California, Berkeley. Specificity: emphasis on research and innovation; students participate in projects that may receive funding from industrial partners.

3. Japan – famous for its robotics industry, and mechatronics training programs reflect this. Study of computer modeling, automated systems and artificial intelligence. Examples of universities: University of Tokyo and Osaka University. Specifics: high emphasis on integrating cutting-edge technologies, such as IoT and artificial intelligence, into curricula; students participate in real-world projects in partnership with Japanese companies.

4. European Union – in EU countries such as Sweden, the Netherlands, Italy, mechatronics programs are quite diverse. Project-based learning methods and interactive learning approaches are often used. Examples of universities: Luleå University of Technology (Sweden) and the University of Twente (Netherlands). Specificity: focused on sustainable development and environmental aspects of

mechatronics; use of an interdisciplinary approach to learning, including aspects of economics and management.

5. Ukraine – mechatronics programs are also growing, but they are often less structured compared to leading countries. Programs usually combine the basics of mechanics, electronics, automation. Examples of universities: Igor Sikorsky Kyiv Polytechnic Institute and Lviv Polytechnic National University. Specificity: focused on theoretical aspects with insufficient emphasis on practice; internship systems are often not as developed as in other countries [24–36, 41].

In turn, mechatronics curricula typically include a wide range of subjects that provide students with the necessary knowledge and skills to work in this interdisciplinary field. Here is a more detailed overview of the core subjects and skills developed during the course of study.

1. Core subjects.

1.1. Mechanics – fundamentals of mechanics, static and dynamic mechanics, mechanics of materials. Skills – understanding the principles of mechanical systems, analysis of forces and moments, design of mechanical elements.

1.2. Electronics – fundamentals of electronics, analog and digital circuits, microprocessor systems. Skills – design and analysis of electronic circuits, understanding the operation of various electronic components.

1.3. Programming – fundamentals of programming (C/C++, Python), algorithms, data structures. Skills – development of software for controlling mechatronic systems, writing scripts for process automation.

1.4. Automation and control – control theory, automated control systems, robotics. Skills – design and implementation of automatic control systems, use of control algorithms (PID, Fuzzy Logic).

1.5. Sensors and actuators – types of sensors (optical, ultrasonic, temperature) and actuators (electrical, pneumatic, hydraulic). Skills – Selection, connection and calibration of sensors and actuators for integration into mechatronic systems.

1.6. Real-time systems – principles of operation of real-time systems, embedded systems. Skills – software development for embedded systems, task execution time management.

2. Additional subjects.

2.1. Mathematics and physics – linear algebra, differential equations, classical mechanics. Skills – mathematical modeling of mechatronic systems, analysis of physical processes.

2.2. Computer graphics and CAD systems – basics of computer graphics, design in CAD systems (AutoCAD, SolidWorks). Skills – creation of 3D models of mechanical structures, visualization of projects.

2.3. Engineering economics and management – basics of project management, engineering economics. Skills – project cost estimation, resource management in mechatronic projects.

3. Practical training.

3.1. Laboratory work – performing laboratory practices that include designing and testing mechatronic systems. Skills – developing practical skills in working with real devices, debugging systems.

3.2. Project activities – working on projects that include developing, implementing and testing mechatronic solutions. Skills – teamwork, project management, critical thinking and a creative approach to solving problems.

3.3. Internship – in-depth training in real conditions at enterprises or research institutions. Skills – applying theoretical knowledge in practice, adapting to the conditions of working in a team [37–40].

Therefore, the training of mechatronics specialists varies depending on the country, educational institution and educational culture. It is important to note that in leading countries the emphasis is on integrating theoretical knowledge with practical skills through internships and research projects. While in Ukraine and some other countries there are still problems with the implementation of such approaches, the development of this field continues to grow.

Mechatronics training programs provide a comprehensive approach to training specialists who are able to work at the intersection of mechanics, electronics and programming. Mastering the basic subjects and developing practical skills are critical for a successful career in this dynamic and innovative industry. Qualified specialists can significantly influence the development of new technologies and improve existing solutions in various fields.

4.2. Fundamentals Modeling and Programming of Mechatronic Complexes

Modeling is an important step in the design of mechatronic systems, as it allows you to visualize the operation of the system, identify potential problems and optimize solutions. The main modeling methods include:

1. Systems based on mathematical models: mathematical equations describe the behavior of the system under certain conditions. This allows you to conduct simulations and evaluate how the system responds to different input data.

2. Numerical methods: often used to solve complex problems that cannot be solved analytically. These methods allow you to conduct numerical experiments, which helps to understand how the system functions in different scenarios.

3. Simulation software: tools such as MATLAB/Simulink, SolidWorks, ANSYS allow you to create virtual models. This helps reduce development costs and reduce time to market [37–40].

Different modeling methods have their own approaches, advantages and disadvantages. Here is an overview of the main methods.

1. Analytical modeling – involves mathematical models that describe a system using differential equations or algebraic expressions. Advantages: simplicity: allows for obtaining exact solutions for simple systems; speed: models are easily solved mathematically without the need for computer resources. Disadvantages: limitations: not suitable for complex, nonlinear systems; uncertainty: difficult to take into account all parameters and variations in the real world.

2. Numerical modeling – the use of numerical methods (e.g., finite element methods) to solve complex equations describing mechatronic systems. Advantages: flexibility: suitable for modeling complex systems with nonlinear properties; detail: can take into account different operating conditions and material characteristics. Disadvantages: time-consuming: numerical models can require significant computational resources and time; complexity: creating and configuring models can be a labor-intensive process.

3. Simulation modeling – using software (such as MATLAB/Simulink, AnyLogic) to create virtual models of systems and their behavior in real time. Advantages: visualization: the ability to visually analyze the behavior of the system; interactivity: allows you to change parameters and track the impact of these changes on the system. Disadvantages: resource requirements: working with large models requires powerful computers; reliability: results depend on the quality of the model and the correctness of the assumptions made.

4. Control system modeling – involves modeling a control system to assess its effectiveness. PID control or neural network methods are often used. Advantages: increased efficiency: allows you to optimize control algorithms in real time; adaptability: systems can independently adjust their behavior depending on changing conditions. Disadvantages: complexity of implementation: requires in-depth knowledge of control theory and algorithms; testing: requires a lot of time to set up and test models.

5. Physical modeling – using physical prototypes or scaled models to test a system in real-world conditions. Advantages: Realism: Provides accurate data about the behavior of the system in the real world; Hands-on experience: Allows students and engineers to gain hands-on experience with systems. Disadvantages: Cost: Creating physical models can be expensive and resource-intensive; Limited flexibility: Difficult to make changes after the model is created.

Modeling methods in mechatronics have different approaches that can be chosen depending on the research objectives, available resources and system complexity. Each method has its own advantages and disadvantages, which requires specialists to carefully approach the selection of the appropriate modeling technique for specific tasks. The mixed use of these methods can provide a more comprehensive analysis and optimization of mechatronic systems.

Simulation plays a critical role in the development of mechatronic complexes, allowing engineers to visualize, analyze and optimize their designs before physical implementation. Case studies of real projects show that modeling helps reduce the number of errors at the production stage and improves the quality of the final product. For example, in the automotive industry, structural modeling can prevent accidents associated with incorrectly designed systems. Let's look at some real-world examples of successful use of modeling in mechatronic system design:

1. Designing a cleaning robot

Company: iRobot (manufacturer of Roomba)

Case description: iRobot uses complex models to design its robot vacuum cleaners, including Roomba. The company uses simulation modeling techniques to test navigation algorithms and sensor systems.

Modeling:

– Methods: iRobot uses MATLAB/Simulink software to model motion trajectories and interactions with the environment.

– Process: Create virtual models of homes in which the robot's movements are simulated. This allows Roomba to analyze how it reacts to various obstacles, such as furniture, and adapt its navigation.

Results:

– Significantly reduced prototype testing time.

– Improved navigation performance, leading to increased sales and positive user feedback.

2. Manufacturing Process Automation

Company: Siemens

Case Description: Siemens uses simulation to optimize its automated production lines. With virtual models, companies can plan new production processes with maximum efficiency.

Simulation:

– Methods: Using a computer-aided design (CAD) system and discrete event modeling software (e.g. AnyLogic).

– Process: Creating digital twins of production lines that allow for real-time analysis of system performance.

Results:

– Reduced downtime and increased productivity by 15%.

– Optimized resource utilization, resulting in lower costs.

3. Medical Robot Simulation

Company: Intuitive Surgical (manufacturer of the Da Vinci system)

Case Description: Intuitive Surgical uses simulation to design its surgical robots, allowing for increased precision and safety of operations.

Simulation:

– Methods: Modeling the movement and interaction of instruments with patient tissue using physical simulations.

– Process: creating virtual models of surgical procedures, allowing surgeons to practice operations in a safe environment.

Results:

– Reducing the risk of complications during operations due to improved training of surgeons.

– High precision of manipulations, which increases the overall efficiency of surgical treatment.

4. Automated control systems

Company: Honeywell

Case description: Honeywell uses modeling to develop control systems in industry, which allows them to optimize their operation and increase safety.

Modeling:

– Methods: using numerical methods and software to simulate system dynamics.

– Process: creating models that simulate the behavior of the system under different conditions (e.g., system failures, pressure drops).

Results:

– Improved ability to predict possible emergency situations.

– Reducing system maintenance costs due to early detection of problems.

5. Development of autonomous vehicles

Company: Tesla

Case description: Tesla is actively using modeling to develop its autonomous vehicles. Models allow for the analysis of sensor data and real-time decision-making.

Modeling:

– Methods: Simulating the operation of autonomous driving algorithms in various road situations.

– Process: Creating a virtual environment for testing the autopilot, including various scenarios such as changing weather conditions and the behavior of other road users.

Results:

– Increased road safety due to accurate control algorithms.

– Successful reduction in the number of accidents related to the human factor [15–23].

Using simulation in the design of mechatronic systems allows companies to optimize their processes, reduce costs and increase safety. Real-world examples such as iRobot robots, Da Vinci medical systems, Siemens automated production lines, Honeywell control systems and Tesla autonomous cars demonstrate how simulation has become a critical tool in the development of innovative technologies. This emphasizes the need to train professionals who can effectively use these methods in their work.

In turn, programming is a critical aspect of mechatronics, as it determines how systems interact with their environment. Key aspects of programming:

Programming languages: Students should be familiar with various programming languages, such as C, C++, Python and specialized languages for embedded systems. Each of these languages has its own advantages and specific uses.

Embedded systems programming: This is an important component of mechatronics, which includes the development of programs for microcontrollers, FPGAs and other embedded platforms. Such systems are used in a variety of applications - from automotive to medical devices.

Implementation of projects based on specific programming languages demonstrates how properly written code can increase the efficiency of mechatronic complexes. For example, programming for controlling the movement of a robot may include algorithms that take into account the physical properties of objects.

In the field of mechatronics, various programming languages are used, each of which has its own characteristics and specific applications. Let's consider the most popular programming languages in this field, their advantages, disadvantages and areas of application.

1. C/C++

Features:

C is one of the oldest programming languages that provides low-level access to hardware.

C++ is an object-oriented language that extends the capabilities of C by providing encapsulation and inheritance mechanisms.

Application:

– Used in the development of embedded systems, controllers and robotics.

– Often used in real-time to work with sensors and actuators.

Advantages:

– High performance and memory efficiency.

– Extensive library of ready-made solutions (e.g., ROS – Robot Operating System).

Disadvantages:

– Difficulty in learning, especially for beginners.

– Less safe compared to modern languages (e.g., the danger of buffer overflow).

2. Python

Features:

– A high-level language characterized by simplicity of syntax and readability.

– Has powerful libraries for data processing and machine learning.

Applications:

– Widely used for the development of data processing algorithms, robot control, and sensor data analysis.

– Used for educational purposes due to its simplicity.

Advantages:

– Easy to learn and write code quickly.

– A large number of libraries (e.g., NumPy, SciPy, OpenCV) for working with data.

Disadvantages:

– Lower performance compared to C/C++.

– Not suitable for tasks where real execution speed is important (although built-in modules in C can be used).

3. MATLAB

Features:

– A numerical computing environment that includes a programming language.

– Has advanced functions for modeling, analysis and data visualization.

Applications:

– Used for modeling mechatronic systems, signal processing, control and automation.

– Widely used in academia and research projects.

Advantages:
– Intuitive interface and ease of use.
– Support for numerical methods and algorithms.
Disadvantages:
– Commercial product that requires a license.
– May be less efficient for large systems.
4. LabVIEW
Features:
– A graphical programming language that allows you to create programs by connecting blocks.
– Specifically designed for test and measurement automation.
Application:
– Used in industrial automated systems, for control and monitoring.
– Widely used in scientific research, laboratory automation.
Advantages:
– Visual approach to programming, which makes it easier to understand processes.
– Convenient for rapid prototyping.
Disadvantages:
– High cost of licenses.
– Less versatile compared to text-based programming languages.
5. VHDL/Verilog
Features:
– Hardware description languages (HDL) used to model electronic systems.
– Allow to design digital circuits at the register and circuit levels.
Application:
– Used to design FPGAs and ASICs in mechatronic systems.
– Used in the development of controllers, signal processing.
Advantages:
– Allows to accurately model the behavior of equipment.
– Suitable for designing complex digital systems.
Disadvantages:
– Requires in-depth knowledge in the field of electronics.
– Complexity of syntax for beginners [37–40].

The choice of programming language for mechatronics depends on the specifics of the project, performance requirements and availability of resources. C/C++ and Python are the main languages for developing embedded systems and algorithms, while MATLAB and LabVIEW provide convenience for modeling and automation. VHDL and Verilog are necessary for hardware design. Knowledge of several languages and the ability to combine them in projects are critical for successful work in the field of mechatronics.

Programming is also a critical component in the development of mechatronic complexes, as it provides control and management of mechanical and electronic elements. Let's consider several specific projects where programming is implemented in various mechatronic complexes.

1. Da Vinci Robotic Surgical System

Project description: The Da Vinci system from Intuitive Surgical is a high-tech surgical robot that allows surgeons to perform minimally invasive operations.

Programming implementation:

– Programming language: C++ for implementing control algorithms.

– Programming: Creation of 3D models and simulations for training surgeons, as well as development of software for controlling instrument movements.

– Functions: Automation of instrument positioning, ensuring accuracy of manipulations through feedback from sensors.

Result: Significantly increased accuracy of operations and reduced risk of complications due to improved software.

2. Autonomous ground robot (AGV)

Project description: autonomous ground robots are used in warehouses and production facilities to transport materials.

Programming implementation:

– Programming language: Python for developing navigation and control algorithms.

– Programming: Use of image processing algorithms for environmental recognition, as well as algorithms for route planning.

– Functions: Autonomous navigation using LIDAR sensors, processing data from cameras, traffic control.

Result: Ensuring efficient logistics at enterprises, reducing labor costs.

3. Production automation system

Project description: Automated production systems are used to optimize processes in industry.

Programming implementation:

– Programming language: Ladder Logic in the PLC (Programmable Logic Controller) environment.

– Programming: Development of control logic for automating various stages of production, including quality control and conveyor control.

– Functions: Monitoring equipment status, machine operation control, implementation of a safety system.

Result: Increased production productivity and improved product quality through automated control systems.

4. Intelligent health monitoring system

Project description: Health monitoring systems are used to monitor physiological indicators of patients in real time.

Programming implementation:

– Programming language: Java for mobile applications, as well as C for embedded systems.

– Programming: Development of algorithms for processing data from medical sensors (ECG, pulse rate) and transmitting them to a mobile application.

– Functions: Analysis of the received data, notification of the user about changes in health indicators.

Result: Increasing patients' awareness of their health status and the ability to respond to critical changes in a timely manner.

5. Robotic manipulator

Project description: Robotic manipulators are used in industry to perform tasks such as welding, assembly and packaging.

Programming implementation:

– Programming language: C++ or Python for control algorithms.

– Programming: Development of programs to control the movement of the manipulator, taking into account dynamics and kinematics.

– Functions: Performing complex movements with high accuracy, processing feedback from sensors for trajectory correction.

Result: Significantly increased efficiency of production processes, reduced human errors [15–23, 37–40].

Therefore, programming is an integral part of mechatronic complexes, ensuring their efficiency and functionality. Real projects such as surgical robots, autonomous ground robots, automated production systems, health monitoring systems and robotic manipulators demonstrate how programming is implemented to achieve specific goals in various industries. The ability to develop and implement software for mechatronic systems is critically important for specialists in this field.

Also important is knowledge of the basics of embedded systems programming, which allows you to integrate software with hardware components. Examples of projects implemented using these languages demonstrate how correctly written code can significantly increase the efficiency of mechatronic complexes.

In addition, an important aspect is understanding the principles of real-time programming, which is critically important for systems that must respond to changes in the environment.

4.3. Fundamentals of Controlling Mechatronic Complexes

Control of mechatronic complexes involves the use of various methods and algorithms to ensure the efficiency and accuracy of the system. Main areas:

– PID controllers: a classic control method that provides stability and speed of response. This approach is widely used in industry where accuracy is required.

– Adaptive systems: algorithms that can learn from previous experience. They are able to adapt to changes in the environment, which makes them especially useful in difficult conditions.

– Machine learning: the latest technologies that allow systems to independently improve their results based on the data received. This may include neural networks for pattern recognition or algorithms for predicting system behavior.

Analysis of the latest achievements in the field of artificial intelligence opens up new opportunities for the development of intelligent mechatronic systems. For example, systems that independently determine the optimal parameters for performing tasks can be used in production lines.

Automatic control systems (ACS) play a key role in the mechanization and automation of various processes in industry, transport, energy and other areas. They can be classified into different types depending on the structure, operating principle and application. In this section, we will consider the main types of automatic control systems and compare their features:

1. Simple automatic control (PID control)

Description: PID (proportional-integral-derivative) systems are used to regulate processes where a setpoint value (e.g. temperature, pressure) needs to be maintained.

Advantages: ease of implementation and tuning; high efficiency for linear systems.

Disadvantages: limited capabilities in nonlinear systems; requires accurate process models for optimal tuning.

2. Automated control systems (ACS)

Description: Process control systems (PCS) integrate various automation elements, including sensors, actuators and software.

Advantages: ability to integrate with different process systems; flexibility in tuning for different processes.

Disadvantages: high implementation cost; complexity of tuning and maintenance.

3. Neural Network-Based Control Systems

Description: These systems use machine learning and artificial intelligence algorithms for adaptive process control.

Advantages: ability to learn and adapt to changing conditions; high efficiency in complex, nonlinear systems.

Disadvantages: need for a large amount of data for training; difficulty in understanding and configuring models.

4. Distributed Control Systems (DCS)

Description: DCS are used to manage large and complex production processes, where control is carried out through the distribution of controllers throughout the system.

Advantages: possibility of centralized monitoring and control; high reliability due to distribution.

Disadvantages: complexity in implementation and maintenance; cost of system implementation.

5. PLC-Based Control Systems (Programmable Logic Controllers)

Description: PLCs are used to automate machines and production processes by programming logic.

Advantages: reliability and durability in industrial conditions; ease of programming and configuration.

Disadvantages: Limited capabilities for complex control algorithms; not always optimal for rapidly changing processes.

6. Fuzzy Logic Control Systems

Description: These systems use fuzzy logic to make decisions under uncertainty.

Advantages: Ability to work with incomplete or inaccurate data; flexibility in configuring the system.

Disadvantages: Difficulty in configuring fuzzy logic rules; may be less effective for simple, well-defined tasks [13–23].

Table 2.3.1

Comparison of automatic control systems

System type	Advantages	Disadvantages
PID control	Simplicity, high efficiency	Limited possibility in nonlinear systems
SUTP	Integration with various technologies	High cost, difficult to maintain
Нейронні мережі	Adaptability, high efficiency	Need for big data, complexity of setup
DCS	Centralized control, high reliability	Complexity of implementation, high cost
PLC	Reliability, ease of programming	Limited capabilities for complex algorithms
Fuzzy Logic	Flexibility, ability to work with uncertainty	Difficulty in setting up rules

The choice of an automatic control system depends on the specifics of the tasks, operating conditions and economic factors. Each type of system has its own advantages and disadvantages, so it is important to carefully assess the project requirements to ensure the effectiveness and reliability of the selected system. In modern mechanized and automated processes, a combination of different systems is often used to achieve optimal results.

Thanks to the latest achievements in the field of artificial intelligence (AI), a significant evolution is taking place in the control of mechatronic complexes. AI introduces innovations that increase the efficiency, accuracy and adaptability of systems. Let's consider several main aspects of the impact of AI on mechatronics:

1. Adaptive control. AI provides the possibility of adaptive control, where systems can independently adjust their parameters depending on the operating conditions. This is especially important in dynamic environments where external factors can change quickly.

Example: autonomous robots that use machine learning algorithms to adapt to new obstacles or route changes.

2. Predictive maintenance. AI can analyze data from sensors and determine when maintenance is needed, which can help avoid failures and reduce downtime.

Example: In industrial machinery, AI systems can analyze vibrations, temperature, and other parameters to predict failures.

3. Process optimization. AI algorithms, such as genetic algorithms or particle swarm optimization algorithms, can improve management and planning processes.

Example: Route optimization for autonomous vehicles in warehouses, which leads to reduced travel times and increased efficiency.

4. Complex data processing. AI allows processing of large amounts of data from various sensors, which improves the accuracy of control and decision-making.

Example: In health monitoring systems, where AI analyzes data from medical sensors and provides doctors with real-time recommendations.

5. Improved user interaction. AI-based systems can improve user interaction using natural language and graphical interfaces.

Example: interfaces for controlling robots that allow users to give commands in language or through simple graphical elements, making the system more accessible.

6. Intelligent control systems. AI can be integrated into control systems, allowing for the implementation of complex control strategies, taking into account changes in the environment.

Example: Systems that use computer vision to identify objects and automatically adjust the operation of mechanisms depending on the situation.

Therefore, the introduction of artificial intelligence into the control of mechatronic complexes opens up new horizons for optimization, safety and efficiency. Adaptive systems, predictive maintenance, improved data processing and user interaction are just some of the many benefits that AI can provide. These technologies not only increase productivity, but also change the way people interact with machines, forming a new era in mechatronics.

Based on the above, we will develop recommendations for the training of specialists in the field of mechatronics.

Training mechatronics specialists is critical for the successful implementation of projects in this dynamic and technologically advanced field. The following recommendations are offered to improve the training of future specialists:

1. Integration of theory and practice. Provide more practical classes where students can work with real mechatronic systems. Introduce laboratory work, internships at enterprises and projects that allow students to apply theoretical knowledge in practice.

2. Interdisciplinary approach. Expand curricula to include courses from related disciplines, such as electronics, computer science and mechanics. Create courses that combine knowledge from different fields so that students can better understand the integration of different components of mechatronic systems.

3. Use of modern technologies. Integrate the latest technologies such as artificial intelligence, IoT (Internet of Things) and robotics into the curriculum. Develop courses in programming, data processing and artificial intelligence so that students can work with modern technologies.

4. Development of soft skills. Training of specialists should include the development of soft skills, such as teamwork, communication and project management. Implement trainings and group projects where students can practice these skills.

5. Cooperation with industry. Involve enterprises in the educational process to train specialists who meet market needs. Create partnerships with companies for joint projects, internships and inviting specialists to lectures and seminars.

6. Continuous learning and improvement. Encourage specialists to continuously learn and improve their skills in a rapidly changing industry. Offer short-term courses, webinars and certification programs for professionals.

7. Project activities. Involve students in real projects where they can work on specific tasks. Organize competitions, hackathons and teams to work on innovative projects.

Improving the training of specialists in the field of mechatronics requires a comprehensive approach, including the integration of theoretical knowledge with practical skills, interdisciplinarity, the use of new technologies and the development of soft skills. Cooperation with industry and the involvement of real projects are also important for training competitive specialists who are ready for the challenges of the modern market.

Therefore, the training of specialists in the field of mechatronics is critically important for innovation and the development of modern technologies. Since the industry is constantly evolving, it is important that curricula adapt to new requirements and challenges. This will ensure the country's competitiveness on the global stage and contribute to the successful development of industry, science and technology. Investments in education in this area will be the key to a successful future, which will contribute not only to economic growth, but also to improving the quality of life.

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CHAPTER 2. INNOVATIVE AND MODERN FOUNDATIONS OF PEDAGOGY AND PSYCHOLOGY

2.1. Nataliia Kostruba PSYCHOLOGICAL WELL-BEING OF MENTAL HEALTH SERVICE PROVIDERS IN UKRAINE DURING THE WAR

The war affected the psychological well-being of Ukrainians and the system of providing mental health benefits is overloaded. The overwhelming majority of the interviewed mental health professionals noted the increase in work load. The largest load falls on such service areas as: education, social sector and culture. Mental health workers in Ukraine play an indispensable role in supporting a population. So, investing in the support and resilience of these professionals, Ukraine can strengthen its overall capacity to heal and rebuild in the face of ongoing adversity.

Keywords: mental health, mental health awareness, war, psychological well-being, migrants.

CHAPTER 3. SCIENTIFIC VIEWS ON LAW AND HISTORY

3.1. Oleg Morozov, Anastasia Strukulenko ARCHAEOLOGY OF INTERNATIONAL TRADE IN ANCIENT EGYPT (III MILLENNIUM BC - III CENTURY BC)

The paper examines the process of formation and development of international trade exchange on the example of ancient Egypt. Based on the above, the work is structured in such a way that at the first stage the main trends of ancient trade in the Middle East, in the basins of the Mediterranean and Red Seas are analyzed and the place and role of the Egyptian kingdom in this process is determined. Subsequently, the author reconstructs the land and sea trade of Egypt, and a separate section is devoted to the history of shipbuilding in ancient Egypt. The study of the problem is based on the analysis of archaeological sources introduced into scientific circulation.

Keywords: trade, archeology, shipbuilding, customs duties, goods, civilization.

CHAPTER 4. Serhii Onyshchenko, Victoriia Zhyhir, Oleksandr Antonenko TRAINING OF SPECIALISTS IN MODELING, PROGRAMMING AND CONTROL OF MECHATRONIC COMPLEXES

Mechatronics is the integration of mechanics, electronics, computer science and control systems, which allows you to create complex automated systems. It arose in the middle of the 20th century, when new technologies became necessary to automate production processes. With the development of computer technology and electronics, mechatronics became the basis for the creation of robotic systems, drones, medical devices and smart home technologies. In the modern world, mechatronics is an important component of many innovations that ensure efficiency, accuracy and safety.

Given the rapid development of the industry, the demand for specialists with knowledge in all these disciplines has increased. Training specialists in the field of mechatronics not only increases the country's competitiveness on the world stage, but also ensures the successful development of industry, science and technology.

Keywords: mechatronics, modeling, programming, design, automation, control systems, intelligent systems, education, training of specialists.

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