Revitalisation of Old Hydraulic Press Brake Machines Through Novel Software Solutions

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Abstract: In the era of Industry 4.0, the modernization of traditional machines has become crucial for maintaining competitiveness and enhancing production capacities. Hydraulic CNC press machines manufactured in the Balkans, particularly in the former Yugoslavia, renowned for their robustness and reliability, are increasingly falling behind in terms of the technological innovations required to meet modern production demands. Rather than being replaced by expensive new machines, this paper presents a transformative approach to the digital upgrade of existing systems. By employing advanced software solutions and novel control methods, older presses are converted into high-precision, intelligently managed machines capable of automatically adjusting operating parameters according to material and task specifications. This system not only significantly reduces operational costs but also extends the lifespan of these machines, increases production speed and minimizes errors. The core innovation of the system is its adaptability, enabling continuous evolution and seamless integration of new technological advancements without requiring substantial investments in entirely new equipment. This paper offers a vision of the future where digital transformation allows traditional machines to become part of smart, interconnected production lines.

Keywords: Hydraulic Press Brake Machine; ESP32; NodeMCU; Desktop Application; C# .NET; WPF

Introduction

Over the past few decades, industrial manufacturing has undergone profound and continuous changes, primarily driven by rapid technological advancements. With each new wave of innovation, companies around the world are challenged to optimize production capacity, enhance efficiency, and reduce operational costs, all while adapting to the demands of an increasingly dynamic and competitive global market. In this context, the concept of *Industry 4.0* has emerged as a key driver of industrial transformation. *Industry 4.0* integrates technologies such as automation, the Internet of Things (IoT), artificial intelligence (AI) and digital connectivity into traditional industrial processes, creating smart, interconnected systems that can independently manage, adjust, and optimize operations in real-time.

Within this technological framework, digital transformation becomes an essential tool for companies seeking to remain competitive, reduce costs, and improve performance. It facilitates the transition from manual and often imprecise processes to fully automated, intelligent systems that optimize production capacities, increase manufacturing speed and enable more efficient use of resources. These benefits allow companies to meet the increasingly complex demands of consumers and markets. However, despite the clear advantages, industrial businesses are struggling with digital transformation. [1]

The research presented in this paper aims to address key questions related to the challenges and opportunities of industrial machine digitalization, with a focus on CNC hydraulic press machines:

1. How can software enhance press machine operation?

2. What components were utilized and how was the software developed?

3. How can digital transformation reduce operational costs and increase press efficiency without requiring significant financial investments?

METHODS AND MATERIALS

In modernizing hydraulic CNC press machines, an integrated approach utilizing both hardware and software advancements was employed to achieve precise control, enhanced automation, and increased operational efficiency.

The ESP32 microcontroller functions as the primary control unit for the CNC hydraulic press machine, managing real-time control tasks and interfacing directly with the machine's critical operational components. ESP32 is ideal for precise adjustments and control necessary for high-precision hydraulic press operations, supporting the automation and accuracy required in industrial environments.

Closed-loop stepper motors were selected for accurate backgauge positioning. Unlike open-loop systems, closed-loop control detects and adjusts any deviation from the intended position, which is critical in maintaining the accuracy required for high-production environments. These motors reduce errors in positioning, ensuring consistent precision without needing continuous manual adjustments.

For effective data exchange between the application and the press hardware, the UART (Universal Asynchronous Receiver-Transmitter) protocol was implemented. This asynchronous protocol facilitates reliable, serial communication, ensuring that commands and responses are transmitted accurately between the microcontroller and control interface. The use of UART in this setup allows for real-time data flow essential to maintain synchronization between software commands and hardware responses.

The GUI (Graphical User Interface) plays a pivotal role in operator interactions, enabling straightforward control over press functions. Designed with an intuitive layout, it includes combo boxes for tool selection and numeric keypads for setting precise measurements. The GUI simplifies operator tasks by automatically adjusting tool parameters and incorporating real-time validation checks, enhancing usability.

To ensure operational safety and accuracy, the software incorporates input validation for key parameters, such as position limits (e.g., the 0-800 mm range for backgauge movement). This functionality prevents erroneous inputs, minimizing operational risks, and contributing to system reliability. Error messages or warnings are generated when values exceed permissible limits, helping maintain machine integrity.

For hands-free operation, especially useful when handling large materials, a foot switch system was integrated. The dual-switch setup allows operators to select preconfigured register settings with one switch and confirm execution with the other, providing flexibility in control without compromising safety.

Safety mechanisms were also incorporated, such as automated shutdown in the event of malfunction or irregular operation. These features align with safety standards, ensuring that the system complies with industrial safety requirements.

Each of these technologies was selected based on its ability to meet the demands of high-precision, efficient, and reliable hydraulic CNC press operation. The combined use of these hardware and software components ensures that the system operates within optimal parameters, enhancing both functionality and operator control.

DISCUSSION

Modern industry faces a significant challenge in updating legacy production machinery, which has been fundamental to manufacturing operations for decades. Hydraulic press machines, crucial tools in fields such as metalworking, automotive manufacturing and heavy machinery, serve as a prime example of this issue. These machines are valued for their robustness, durability, and longevity, allowing them to function effectively for many years with minimal maintenance. However, even though their mechanical performance remains commendable, they have become technologically outdated when compared to contemporary CNC (Computer Numerical Control) systems, which deliver superior precision, speed, and flexibility through digital control.

The Industry 4.0 trend poses many challenges for the manufacturing industry and societies generally. [2] The trend presents new challenges and opportunities related to industrial competitiveness and sustainability, as industrial firms adopt digital technologies to change how they interact and exchange data across their industrial network. [3] The challenge many enterprises face is how to retain the advantages of their existing hydraulic press machines while simultaneously improving efficiency, accuracy and productivity to meet the demands of modern market. Traditional hydraulic press machines often depend on manual controls, which can be slow, prone to errors as well as limited in accuracy and speed when adjusting to different materials and production conditions. In contemporary production environments, such systems can create bottlenecks that limit flexibility and diminish overall productivity.

For firms dealing with industrial customers, Industry 4.0 is about how firms can create solutions that help their industrial customers increase their own productivity. [4] Acquiring new CNC machines equipped with the necessary digital functionalities is not always a feasible option, particularly for small and medium-sized enterprises. Even after more than a decade from the start of the fourth industrial revolution, manufacturing industry still struggles to upgrade to Industry 4.0-compliant technologies and standards. [5] High costs associated with purchase, implementation and staff training to operate new machines often pose significant obstacles for companies and enterprises pursuing modernization. In this context, the digital upgrade of existing hydraulic press machines offers a more cost-effective alternative. Such solutions facilitate the integration of modern software systems, sensor networks, and automated control mechanisms into existing machines, significantly enhancing their performance without the need for complete system replacement.

The digital transformation of hydraulic presses facilitates the automation of processes that previously required manual intervention. For instance, key parameters, such as backgauge movement, can now be automatically controlled by software, resulting in significantly greater speed and efficiency in operation. Additionally, sensor networks that collect real-time data allow the machines to adapt automatically to changing production conditions without manual adjustments. This optimization not only accelerates the production process but also considerably reduces the risk of errors and improves material utilization.

While modernization through digitalization offers numerous benefits, significant challenges persist. Integrating new digital systems with older mechanical components can be technically demanding, requiring a high level of expertise in design and implementation. Careful analysis and adaptation of the compatibility between new control systems and existing mechanical parts are essential to ensure reliable operation. Furthermore, training staff who are accustomed to manual processes can be challenging, as it requires a fundamental shift to entirely new ways of working and thinking. The goal of smart manufacturing or its synonym "Industry 4.0" is to automate manufacturing processes, were fully integrated and collaborative manufacturing systems rapidly can respond to meet the demand and conditions. [6]

This study investigates the potential for the digital transformation of hydraulic press machines, aiming to integrate them into smart production systems within the Industry 4.0 framework. The emphasis will be on the development and implementation of software and hardware solutions that not only enhance efficiency, precision and productivity but also enable significant cost savings through the modernization of existing systems, thereby avoiding substantial financial investments in new machines.

The objective of the research was to develop and implement a software and hardware solution that enables the digitalization of press machine operations, thereby improving efficiency, precision, and productivity while reducing costs and operational errors. This work combines engineering techniques and software development with practical applications in real industrial settings.

This research is focused on a hydraulic CNC press machine produced in the 1990s, which features a traditional manual control system for managing the backgauge position and other operational parameters. This machine, still commonly found in many industrial facilities in the countries of the former Yugoslavia due to its robustness and longevity, lacked capabilities for digital control, remote operation or real-time monitoring.

Prior to digitalization, the machine's operation relied entirely on manual processes, including the manual adjustment of the backgauge. This method was not only slow and time-consuming but also prone to errors, leading to delays that are far from cost-effective in today's industrial landscape.

After thoroughly assessing the existing issues and challenges associated with the manual control of the machine, a comprehensive software and hardware upgrade was implemented. This process involved developing software to enable automated control of the press machine's key operations, including precise adjustments of the backgauge and other operational parameters. As part of the upgrade, guides, lead screws, closed-loop stepper DC motors as well as ESP32 microcontroller using the NodeMCU (Node Microcontroller Unit) development environment were integrated. This enhancement significantly improved the efficiency, precision, and speed of operation, reducing operational errors and downtime, ultimately resulting in an optimized production process without the need for complete machine replacement.

Hardware upgrade

To facilitate the complete digitalization and modernization of the hydraulic press machine, several hardware elements and components were introduced to enable automatic control and monitoring of operational parameters. The key components of the hardware upgrade include the following:

Microcontroller ESP32: The ESP32 microcontroller was selected for its specific features and the NodeMCU (Node Microcontroller Unit) development environment. Its main advantages include the capability to handle multiple tasks simultaneously as well as the inclusion of built-in Wi-Fi and Bluetooth modules, enabling wireless connectivity. This integration facilitates precise control over all aspects of the press machine's operation.

Stepper motors (Closed-Loop): These motors have replaced manual systems for adjusting the backgauge. By utilizing feedback from encoders, the stepper motors enable precise positioning of the backgauge without manual intervention, significantly reducing the time required for adjustments and enhancing operational accuracy.

Guides: Guides were integrated to ensure stable and precise movement of the press's key components, thereby enhancing accuracy during operations and extending the system's lifespan.

Lead screws: Lead screws are essential for transmitting power and movement within the system. Their implementation facilitates precise positioning and minimizes friction and wear during operation.

Software upgrade

The software developed for controlling the hydraulic press employs advanced algorithms to automate and optimize work operations. It was created in the C# .NET environment and features an intuitive user interface based on WPF (Windows Presentation Foundation) technology.

Desktop application for managing the CNC hydraulic press machine

The desktop application developed for managing the hydraulic CNC press machine serves as a critical component of the digitalization and automation process. Developed using the C# programming language as part of the .NET framework, the application utilizes WPF (Windows Presentation Foundation) to create an intuitive user interface. Communication with the hardware components of the CNC press machine is facilitated through the ESP32 microcontroller, which is connected using a serial communication port (Figure 1).

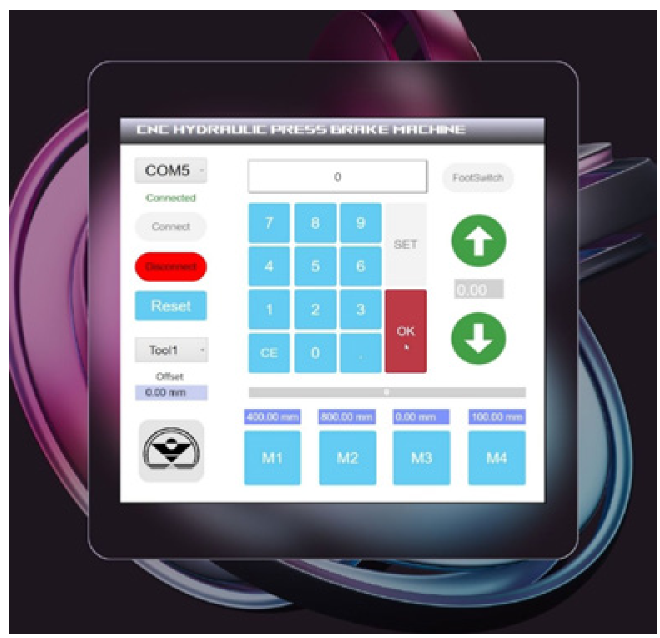

Figure 1. *Press Brake Software. Source: author's contribution*

Main functionalities of the application include (Figure 2):

Automatic backgauge positioning: The application sends commands to the microcontroller for the precise movement of the backgauge according to the input parameters. By utilizing data from position sensors (encoders), the backgauge is automatically positioned correctly, enabling accurate alignment for each operation.

Error handling and exception management: The implementation of try-catch blocks within the software code allows the application to efficiently manage errors related to communication or the operation of hardware components.

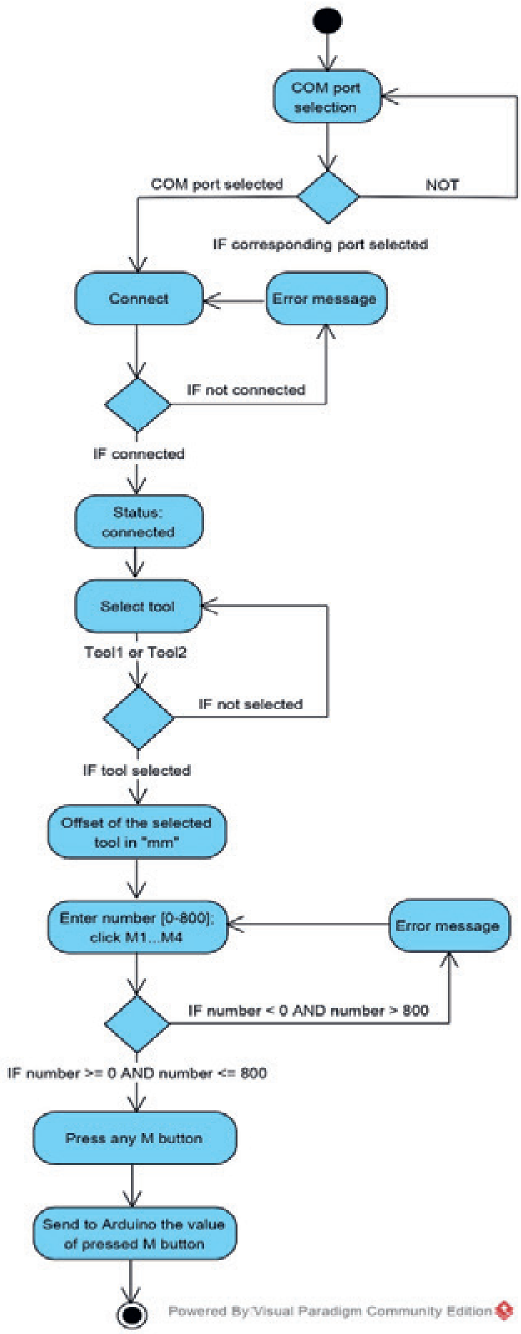

Figure 2. *Flowchart diagram of the PressBrake Software. Source: author's contribution.*

Initialization routine: When the application is launched, a key-value request is generated and sent to the microcontroller. This request initiates the machine's homing sequence, which is carried out using limit switches placed at the ends of the x-axis, where the backgauge moves. The automatic positioning to the home position functionality significantly improves the system initialization process, increasing the speed at which the press machine is prepared for operation and making the process more intuitive and user-friendly for the operator.

Precision and positioning speed: The application is optimized to enable the backgauge to reach the desired position in approximately 2 seconds, with slight variations depending on its current position and the specified input interval. The movement range of the backgauge spans from the machine's home position to a maximum of 800 mm, ensuring consistent precision across its entire range. This functionality is essential, as it allows operators to perform high-precision operations without the need for manual adjustments to the backgauge.

Tool input and selection: The application enables operators to pre-configure and save two tools within the system, each with predefined parameters. These tools can be easily selected through a combo box, which reduces the need for manual parameter input for each task. This functionality facilitates smooth transitions between different types of operations without requiring additional setup, thereby improving work efficiency and reducing cycle time.

User experience is enhanced through the implementation of an intuitive graphical user interface, allowing operators to quickly access key functionalities. The combo box for tool selection enables rapid tool changes with automatic parameter adjustments, minimizing the need for additional calculations during operation. This streamlined interface simplifies the workflow, making the operation more efficient and user-friendly.

Application operation principle

The hydraulic CNC press control application allows users to manage the machine's operational parameters intuitively and efficiently, leveraging modern digital infrastructure. The connection to the press machine's hardware components — such as sensors, motors, and backgauges — is established through a serial communication port, utilizing the UART (Universal Asynchronous Receiver-Transmitter) asynchronous serial protocol to ensure reliable data exchange between the computer and the microcontroller.

Microcontroller connection process

When the application is launched, the user selects the appropriate communication port to establish a connection between the application and the microcontroller. Upon clicking the "CONNECT" button, its color changes from gray to green, indicating that the system is prepared for connection. This visual cue provides the operator with a clear indication of the system's status.

Once the "CONNECT" button is pressed, the application sends an initial request to the microcontroller through the serial port to confirm successful communication. If the microcontroller responds positively, the application displays a message confirming the connection. At this point, the "CONNECTED" button becomes inactive, while the "DISCONNECT" button becomes active and is marked in red, enabling the operator to disconnect the system as needed. This functionality ensures that communication with the microcontroller is correctly established before proceeding with further operations.

In the event of a connection error, the application generates an error message, prompting the user to select a different port. This process, referred to as "handshaking," allows the application to identify the correct device connected to the serial communication port.

Backgauge and tool management

After establishing the connection, the user can select between two predefined tools using the combo box in the application. Each tool is associated with its own specific parameters, including an offset in millimeters from the machine's zero point. For example, "Tool 1" has a zero offset (0.00 mm), while "Tool 2" has an offset of 10.00 mm. This functionality allows the operator to manage tool positioning accurately without the need to manually enter complex parameters, thereby reducing errors and increasing efficiency.

Once a tool is selected, a numeric keypad facilitates the input of the desired position in millimeters. The entered parameters are stored in one of the four available registers (M1, M2, M3, M4) by pressing the "SET" button. After the values are stored in a register, the application transitions to standard operating mode, where the operator can select one of the registers and send the corresponding data to the microcontroller (Figure 3).

The microcontroller subsequently uses this data to position the backgauge according to the entered values. The backgauge operates at a speed of approximately 200 mm/s, with gradual acceleration during the initial 10 mm and deceleration in the last 10 mm before reaching the desired position. This process ensures smooth and precise positioning without abrupt changes, which reduces the risk of material damage.

Limits and input validation

The application incorporates an input validation mechanism to ensure the accuracy and correctness of the press machine operation. If the user enters a value beyond the allowable range (e.g., greater than 800 mm, which is the maximum backgauge movement range), the application generates an error message notifying the user that a valid value must be entered. Similarly, if the user inputs a negative value, the program will display a warning indicating that the value is outside the permissible range (0–800 mm).

This functionality ensures that the machine operates within predefined limits, thereby reducing the likelihood of errors and malfunctions during operation.

Operation using the Foot Switch

An additional feature of the application enables users to control the press using a foot switch. The operator can select one of the four registers with the left foot switch, while the right switch confirms the selected position and triggers the backgauge to move to the specified location. This mode of operation allows operators to control the machine without needing to interact with the screen, which is particularly beneficial when working with large pieces of material that may obstruct access to the screen.

Once the operator finishes using the foot switch, the "Foot Switch" button function allows the application to automatically revert to the standard touch screen operating mode, enhancing the flexibility of machine control.

Figure 3. *User interface of the desktop application. Source: author's contribution*

Reset and error clearing

In the event of an error or the need to restore the system to its default settings, the application includes a "RESET" button that resets all parameters to their initial values. This functionality is particularly useful in situations where previous inputs need to be quickly cleared or when the system requires resetting due to a change in the operational task.

Results

During the modernization process of hydraulic CNC press machines, extensive tests were conducted to evaluate the system's performance and optimize functionality. The tests have revealed significant improvements in the following key areas:

Precision: The system's automation has enabled high positioning accuracy, significantly reducing the likelihood of errors during machine operation.

Operational speed: The optimization of the backgauge and automation of processes have led to a substantial decrease in task completion time, resulting in increased overall machine productivity.

Energy Efficiency: The introduction of new control systems has optimized energy consumption, contributing to reduced operational costs.

System Longevity: Improved control and automatic adjustment of key parameters have minimized the need for frequent manual interventions, thereby extending the machine's lifespan and decreasing the frequency of breakdowns.

Technical architecture of the solution

The digital transformation of industrial machines necessitates the careful and strategic integration of hardware and software components into a cohesive system. The technical architecture of the solution encompasses microcontrollers, actuators, and an advanced software interface, facilitating automatic control and monitoring of the press's operations. This approach enhances efficiency, precision, and overall control of machine operations.

Economic viability of digitalization

Although the digitalization of hydraulic CNC press machines necessitates initial investments in hardware components and software systems, a return on investment (ROI) analysis clearly illustrates the economic benefits. In the first year following implementation, companies can anticipate a reduction in operational costs of up to 30%. Furthermore, increased productivity, reduced downtime and decreased material waste further validate the economic viability of digitalization. Digital transformation requires not only selecting the right technology but also implementing this technology in a company's core. [7]

System safety and security

Safety is a paramount concern when implementing new technologies in industrial machines. All digital systems must be certified in accordance with applicable safety standards. For instance, the automatic machine shutdown system, activated in the event of a malfunction or improper operation, is a crucial component of the safety strategy. Additionally, control systems must be safeguarded against potential hacking attacks to ensure the security of data and machine operations.

This digital transformation provides industrial enterprises with significant enhancements in operational efficiency, long-term cost-effectiveness, and improved safety.

During the digitalization of hydraulic press machines, we encountered several technical challenges, which were successfully addressed through an iterative development approach. One of the main challenges was ensuring the accuracy of backgauge positioning using closed-loop stepper motors.

Testing the system under real industrial conditions confirmed that the automation of backgauge adjustments significantly accelerated the machine's setup process. Prior to modernization, every operational change required manual intervention, which slowed down the production cycle. In contrast, the digitalized system enables faster and more accurate adjustments, directly enhancing productivity.

Feedback from operators who tested the modernized press machine was particularly valuable. Their responses indicated that the new software interface is user-friendly, intuitive and provides greater control over the process. This has reduced the need for extensive training and the introduction of new operating procedures, making the transition from a manual to a digital system smoother.

Although we achieved excellent results, potential for further improvements still remains. For instance, in future iterations, we could explore additional automation possibilities by integrating more sensor networks, allowing for even more precise control of the machine under specific production conditions.

Overall, the modernization of the press machines significantly improved efficiency, reduced costs and provided operators with greater flexibility in their work, enabling companies to leverage modern technology without the need to invest in entirely new machines.

Conclusion

The results of this study confirm that the digital transformation of hydraulic CNC presses is a crucial step toward enhancing performance and efficiency in industrial production. By utilizing modern software and hardware solutions, older machines can be significantly upgraded, extending their operational lifespan and achieving high levels of precision and speed without necessitating substantial capital investments in new equipment.

The implementation of automated systems for backgauge positioning and operational parameter adjustment has led to a reduction in errors and an acceleration of the production process. These advancements enable small and medium-sized enterprises to remain competitive in today's market while also reducing maintenance costs and increasing operational flexibility.

In recent years, Smart Manufacturing which is the core idea of the Fourth Industrial Revolution (Industry 4.0) has gained increasing attentions worldwide. [8] Future development should focus on enhancing algorithms for energy consumption optimization as well as integrating new technologies such as artificial intelligence. This would facilitate even greater automation and real-time adjustments of operational parameters. Recent advancements of several information technologies and manufacturing technologies, such as Internet of Thing (IoT), Big Data Analytics, Artificial Intelligent (AI), Cloud Computing, Digital Twin, Cyber-physical System, etc. have motivated the development of Smart Manufacturing. [9] Further research in these areas could contribute to increased efficiency and longevity of existing industrial machines, making them an integral part of smart production systems within the Industry 4.0 framework, while promoting sustainable development practices.

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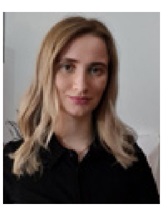
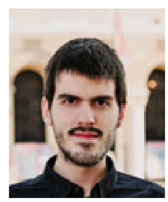
Daniel Menićanin, a student at the Faculty of Information Technology specializing in Programming and Software Engineering at Paneuropean University Apeiron, is an innovator recognized for developing groundbreaking solutions. In recognition of his exceptional contributions to education, science, and the arts, Daniel received the Plaque of the City of Banja Luka. He was also awarded the prestigious Butterfly Innovation Award in the Youth category, presented by the Regional Cooperation Council.Currently, Daniel's research focuses on robotics, industrial machinery, and automation, further advancing his expertise in developing cutting-edge technological solutions.



Jelena Radanović, a dedicated and accomplished student of Programming and Software Engineering at Paneuropean University Apeiron, is widely recognized for her innovative contributions and exceptional achievements in the field. She has received the prestigious Butterfly Innovation Award and the INOST Medal for her project Press Brake Software, showcasing her expertise in software development and creative problem-solving.



Nikola Račić, a talented and forward-thinking student of Programming and Software Engineering at Paneuropean University Apeiron, has earned recognition for his exceptional achievements in innovation and technology. Among his achievements is the prestigious Butterfly Innovation Award, which highlights his outstanding contributions to creative problem-solving and technological advancement. Currently, Nikola is conducting research in robotics and automation, continuing to push the boundaries of innovation and strengthening his position as a key contributor to technological advancements with practical real-world applications.

Dr. Branimir Trenkić, Full Professor in Computer Sciences, was born in Ćuprija, Serbia, in 1961. Dr. Trenkić joined the Faculty of Computer Sciences in Belgrade as associate professor in 2011. In 2013 he became a full professor at the Faculty of Computer Sciences and in 2016 he joined the School of Electrical and Computer Engineering of Applied Studies. Throughout his career, he has authored numerous impactful publications in peer-reviewed journals, contributing valuable insights to the scientific community, projects etc. Area of work: performance analysis of communication networks, high-performance systems (HPC), IoT, queueing strategies for communication networks, software development and testing.

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