Balkan Journal of Applied Mathematics and Informatics
Volume ?? Number ?
Year 201?

Print ISSN ???
Online ISSN ???
UDK: ???

MODELLING, SIMULATION AND SCADA-BASED CONTROL OF AN AUTOMATED SHEET METAL TRANSPORT SYSTEM

SOFIJA JAKIMOVSKA AND SAŠO GELEV

Abstract. This paper presents the modelling, simulation, and implementation of an automated sheet metal transport system with integrated SCADA control. The proposed system is designed to improve the efficiency and reliability of industrial laser processing by replacing manual handling with an automated solution consisting of transport carts, a pusher mechanism, and a transversal unit with vacuum handling. A programmable logic controller (PLC) implemented in the UniLogic environment is used to coordinate all subsystems, including encoders, inductive sensors, and electromechanical actuators. In addition, a mathematical model of the motion control system is developed and analysed using MATLAB/Simulink. The control strategy is based on a cascaded structure with an inner loop for speed regulation and an outer loop for position control. The simulation results demonstrate stable system behaviour, accurate positioning, and fast convergence to the target position with negligible steady-state error. Furthermore, the SCADA system enables real-time monitoring, data logging, and alarm management, enhancing operational efficiency. The proposed approach provides a scalable and reliable solution for industrial automation, combining control theory, simulation, and practical implementation.

1. **Introduction**

Modern industrial manufacturing increasingly relies on automation technologies to improve productivity, precision, operational safety, and process reliability. In sheet metal processing industries, particularly in laser cutting systems, efficient material handling and transport play a critical role in maintaining continuous production flow and minimizing downtime. However, in many existing production environments, sheet transport operations are still partially performed manually, resulting in positioning inaccuracies, synchronization problems, increased operator workload, and reduced overall productivity.

To address these limitations, industrial automation systems based on Programmable Logic Controllers (PLCs), Supervisory Control and Data Acquisition (SCADA) platforms, and Variable Frequency Drives (VFDs) are widely adopted in modern manufacturing processes. PLC-based systems provide reliable real-time control of sensors and actuators, while SCADA platforms enable centralized monitoring, visualization, alarm management, and data acquisition. Recent research has demonstrated the effectiveness of PLC–SCADA integration in industrial automation, material handling systems, and motion control applications. However, many existing approaches primarily focus either on supervisory monitoring or simulation-based analysis, without providing an integrated framework that combines real industrial implementation, motion control verification, and supervisory automation within a unified system architecture.

This paper presents the modelling, simulation, and SCADA-based control of an automated sheet metal transport system developed for industrial laser processing applications. The proposed system replaces manual material handling through the integration of automated transport carts, a pusher mechanism, and a transversal vacuum-based transfer unit coordinated through a Unitronics UniStream PLC in the UniLogic environment. In addition, a mathematical and simulation model of the motion control subsystem is developed in MATLAB/Simulink using a cascaded position–speed control strategy for stable and accurate positioning.

The main contribution of this work is the development of an integrated industrial automation framework that combines PLC programming, SCADA supervision, encoder-based positioning, VFD-driven motion control, MATLAB/Simulink verification, and practical industrial implementation within a single automated transport system. Experimental and simulation results demonstrate improved operational efficiency, reliable positioning performance, and reduced need for manual intervention, confirming the suitability of the proposed approach for modern industrial automation environments.

1.1 **Related work and research contribution**

SCADA and PLC systems are widely applied in industrial automation due to their reliability, flexibility, and real-time monitoring capabilities [1], [2]. Several studies have investigated the integration of PLC and SCADA technologies for industrial automation and manufacturing processes [3]–[5]. Automated material handling and sheet transport systems based on PLC control have also been developed to improve productivity, operational safety, and process efficiency in industrial environments [6], [8].

Recent research focuses on Industry 4.0 integration, smart manufacturing architectures, and advanced supervisory systems for industrial applications [9], [11]. Modern PLC–SCADA systems increasingly incorporate real-time data acquisition, interoperability, intelligent monitoring, and distributed industrial control [9], [13]. In addition, MATLAB/Simulink has become an important tool for modelling and simulation of industrial automation systems and electrical drives before real implementation [7]. Advanced control approaches, including intelligent and fuzzy logic-based load balancing methods, have also been explored for improving manufacturing system performance [12].

Although previous studies demonstrate successful PLC–SCADA implementations for industrial automation and conveyor systems, limited research has focused on integrated automated sheet metal transport systems combining PLC control, SCADA supervision, asynchronous motor modelling, and MATLAB/Simulink verification within a unified industrial framework.

The contribution of this paper is the development of a PLC–SCADA based automated sheet metal transport system for laser processing applications. The proposed system integrates transport coordination, sensor-based positioning, asynchronous motor simulation, and real-time SCADA monitoring into a unified industrial automation architecture. The system aims to improve transport precision, operational reliability, process visualization, and overall production efficiency in modern industrial environments.

2. **System description and operating principle**

The proposed system is designed to automate the transport of sheet metal between storage and laser processing units. It consists of three main subsystems: transport carts, a pusher mechanism, and a transversal unit equipped with a vacuum handling system. The overall layout of the system is shown in Figure 1. The transport carts move along a predefined axis and are responsible for positioning the sheet metal. Once positioned, the pusher mechanism transfers the sheet towards the transversal unit. The transversal unit then lifts the sheet using vacuum suction and transports it to the selected laser machine. The system operates in two modes: manual and automatic. In manual mode, the operator can control individual movements for setup and maintenance. In automatic mode, the system executes a predefined sequence consisting of positioning, pickup, transfer, and placement. Before operation, a calibration procedure is performed to establish reference positions using limit switches and encoder feedback. During operation, sensor data is continuously monitored to ensure accurate positioning and safe operation. This coordinated sequence enables reliable and efficient material handling, reducing human intervention and improving overall system productivity.

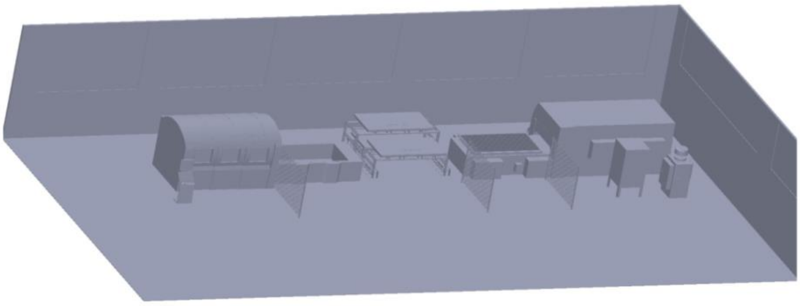

Figure 1. *System architecture of the automated sheet metal transport system, including transport carts and laser machines.*

3. **Electrical and control architecture**

The electrical architecture of the system is designed to ensure reliable power supply, protection, and controlled operation of all subsystems. It consists of power circuits and control circuits integrated into a unified system. The system is supplied from a three-phase 400 V AC network through a main circuit breaker and protection elements. Individual subsystems are connected via dedicated circuit breakers and thermal protections, ensuring safe operation under load conditions. As shown in Figure 2, the transport carts and pusher mechanisms are driven by induction motors (M01–M04) controlled through Variable Frequency Drives (VFD01 and VFD02). The transversal unit is powered by an additional motor (M09) controlled via VFD03. These drives enable speed regulation and directional control of the mechanical motion. The control system is implemented using a PLC, which processes signals from sensors, limit switches, and encoders, and generates commands to contactors, relays, and VFDs. This allows synchronized operation of all subsystems, as well as fault detection and safe shutdown in abnormal conditions. Overall, the integration of power and control circuits ensures stable, safe, and efficient system operation.

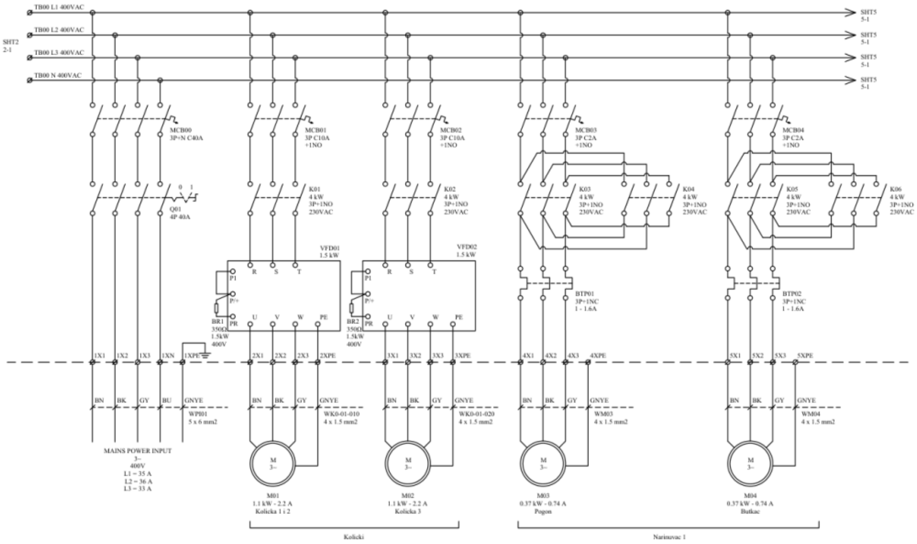

Figure 2. *Electrical architecture of the system, including power supply, protection elements, VFD-controlled motors, and control circuits.*

4. PLC programming and control implementation

The control of the automated system is implemented using a programmable logic controller (PLC) in the UniLogic environment. The program is structured in a modular way, allowing independent control of each subsystem while maintaining synchronized operation. The main program cycle includes input processing, execution of control logic, and updating of output signals. Digital inputs from sensors and limit switches are continuously monitored, while encoder feedback is used to determine the position of moving elements. Based on these signals, the PLC generates control commands for motors, VFDs, and pneumatic actuators. The control logic is organized as a sequence of operations corresponding to the system workflow. In automatic mode, the PLC executes a predefined cycle consisting of positioning of the transport cart, activation of the pusher mechanism, and transfer of the sheet using the transversal unit. In manual mode, the operator can directly control individual components for testing and maintenance. Position control is achieved using encoder-based feedback, enabling accurate movement and repeatability. Speed control is implemented through VFD commands, allowing switching between high-speed and low-speed operation depending on the distance to the target position. Safety conditions are integrated into the control logic, including limit switch verification, fault detection from VFDs, and emergency stop handling. In case of abnormal conditions, the system is immediately halted and an alarm is generated. This implementation ensures reliable, flexible, and safe control of the automated transport system.

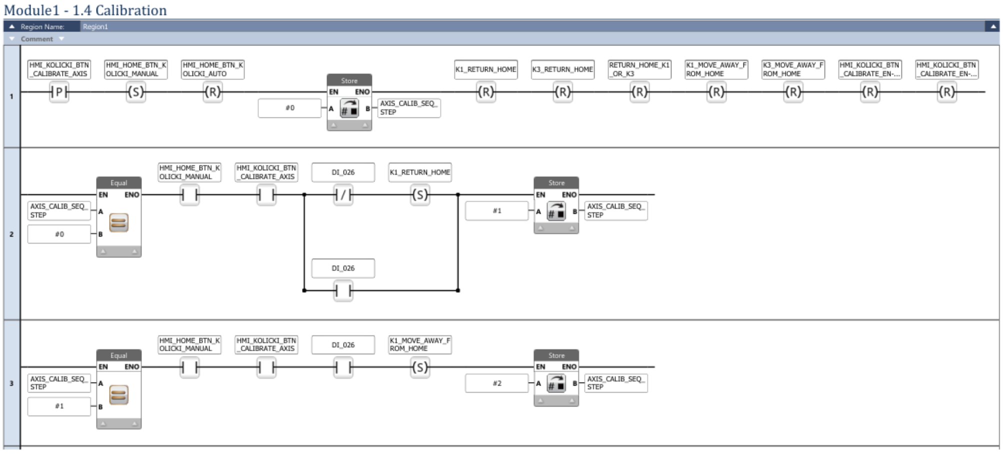

Figure 3. *PLC ladder logic for the calibration sequence of the transport system axes. The program initializes encoder references, performs homing operations, and sequentially controls the movement of transport carts during the calibration procedure.*

5. **SCADA system**

The SCADA system represents the supervisory layer of the proposed automation system, enabling real-time monitoring, control, and data acquisition. It is integrated with the PLC controller via Ethernet communication and provides a graphical interface for operator interaction. The main SCADA interface, shown in Figure 4, presents a unified visualization of all subsystems, including transport carts, the pusher mechanism, and the transversal unit. The operator can select between manual and automatic operation modes, initiate or stop the process, and monitor system states such as positions, sensor signals, and actuator statuses. The SCADA system continuously exchanges data with the PLC, allowing bidirectional communication. It reads input signals from sensors and encoders while sending control commands to motors, VFD drives, and pneumatic actuators. This ensures synchronized operation between the supervisory and control layers. In addition, the system includes data logging functionality, where each operational cycle is recorded with relevant parameters such as execution time, selected subsystem, and system status. This enables performance analysis and supports maintenance planning. Alarm management is also integrated within the SCADA environment. Fault conditions such as drive errors, limit violations, and sensor inconsistencies are detected and displayed in real time. All events are stored for further analysis, allowing improved diagnostics and increased system reliability. Overall, the SCADA system enhances usability, safety, and efficiency by providing centralized supervision and control of the automated process.

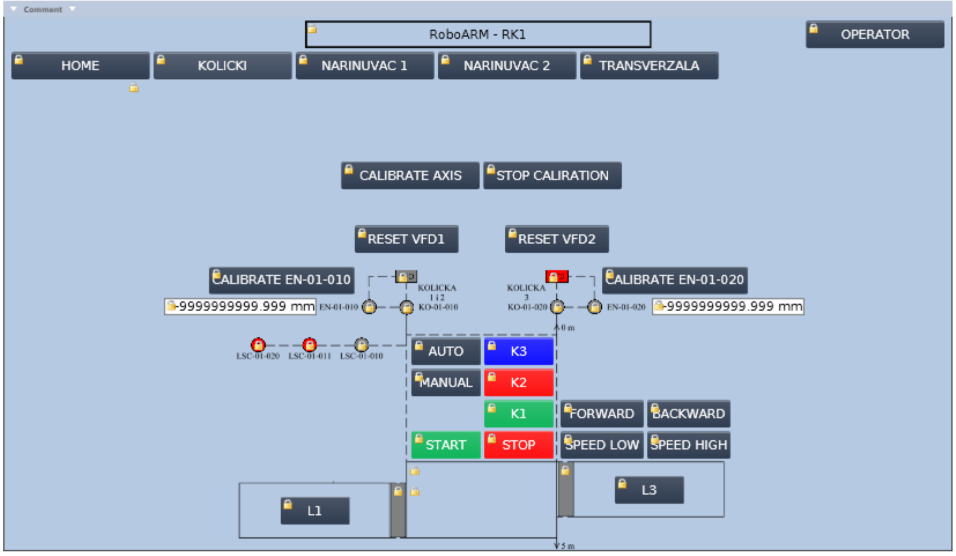

Figure 4. *SCADA/HMI interface of the automated sheet metal transport system showing transport cart positioning, calibration controls, VFD reset functions, and automatic/manual operating modes.*

6. Mathematical modelling, simulation and results

A dynamic closed-loop motion control model of the automated transport system was developed in MATLAB/Simulink in order to analyse the behaviour of the transport carts and validate the proposed control strategy. The simulation model is based on a squirrel-cage asynchronous machine supplied through a three-phase programmable voltage source representing the operation of a variable frequency drive (VFD). The motor parameters used in the model correspond to a nominal power of 18.45 kVA, nominal voltage of 400 V, and frequency of 50 Hz.

The complete simulation structure is presented in Figure 5 and includes the motor dynamics, encoder-based feedback signals, cascaded control loops, mechanical conversion blocks, saturation elements, and stopping logic. The control architecture is implemented as a cascaded system consisting of an inner PID speed-control loop and an outer position-control loop.

The inner loop regulates the motor speed by controlling the motor torque, while the outer loop generates a speed reference according to the position error between the

desired and measured cart position. The position signal is obtained from the motor shaft angle through encoder conversion logic: $x[mm] = \frac{\theta}{2\pi} C$
where $C = \pi D$ represents the mechanical conversion constant between rotational and linear motion. In the simulation model, a wheel diameter of $D = 100mm$was used, resulting in a conversion constant of approximately 314 mm.
To achieve realistic industrial operation, several physical constraints were introduced into the model. The reference speed was limited through saturation blocks corresponding to the maximum VFD operating frequency of 30 Hz, while the PID controller output torque was limited to ±200 Nm in order to avoid unrealistic acceleration and integral wind-up effects. The final controller parameters used in the simulation were:

- $K_p = 0.9$
- $K_i = 0.4$
- $K_d = 0$

The simulation was performed using the variable-step ode23tb solver with a total simulation time of 10 s. During the simulation, the transport cart moved from the home position (0 mm) toward the target End position (1800 mm). A switching condition was implemented so that once the position reached: $x \geq 1800mm$
the reference speed was automatically forced to zero, producing a controlled stop without oscillatory behaviour.
The obtained simulation results are shown in Figures 6 and 7. The position response demonstrates a smooth monotonic increase toward the target position with practically negligible steady-state error and without significant overshoot. The speed response shows smooth acceleration during the initial motion phase followed by gradual deceleration as the cart approaches the final position. The settling time of the system was approximately 6 s, while the final position error remained close to zero. These results confirm that the proposed cascaded PLC–SCADA-oriented control strategy provides stable operation, accurate positioning, and reliable dynamic performance suitable for industrial automated transport applications.

Table 1. *Main simulation and control system parameters used in the MATLAB/Simulink model.*

Parameter	Value
Nominal voltage	400 V
Frequency	50 Hz
Motor type	Asynchronous motor
Wheel diameter	100 mm
Maximum position	1800 mm
PID controller	Cascaded PID
Simulation time	10 s
Solver	ode23tb

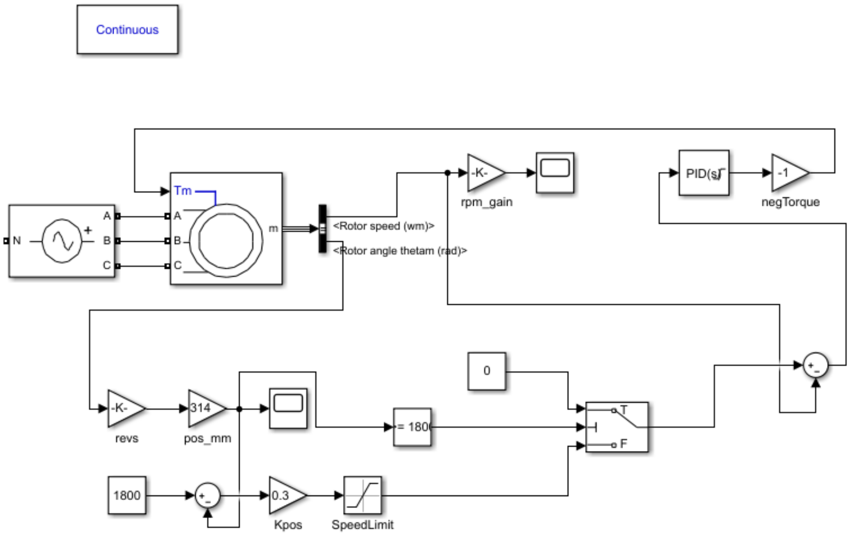

Figure 5. *MATLAB/Simulink model of the automated sheet metal transport drive system incorporating the asynchronous motor model, cascaded PID-based position and speed control loops, encoder feedback, and linear position conversion blocks.*

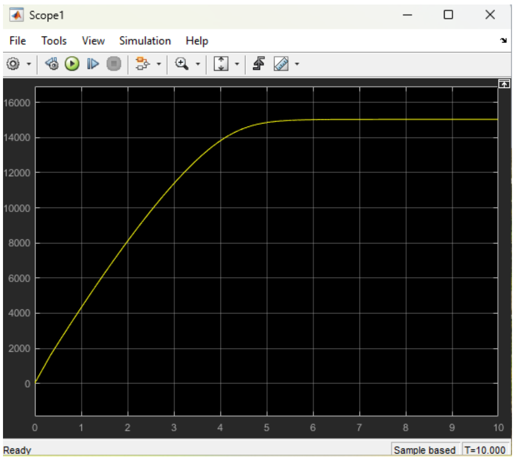

Figure 6. *Position response of the system.*

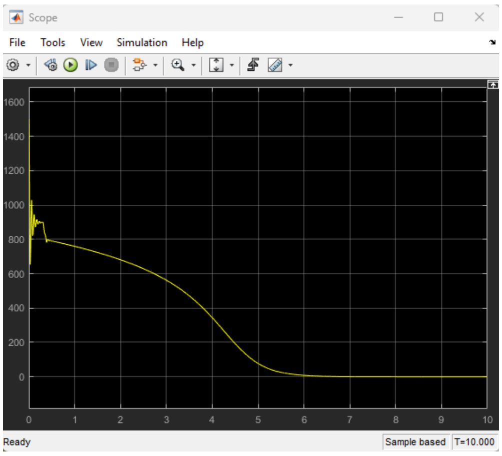

Figure 7. *Speed response of the system.*

7. System implementation

The proposed system was physically implemented and tested in an industrial environment for automated sheet metal handling. The implementation includes mechanical structures, electric drives, sensors, and a centralized PLC-based control system. Figure 8 shows the transversal unit with a vacuum handling system used for lifting and transporting sheet metal. The vacuum cups ensure stable gripping and precise placement during operation. Figure 9 presents the laser cutting machine where the processed sheets are positioned. The mechanical transmission system is based on chain-driven mechanisms and electric motors, as shown in Figure 10. These components enable controlled linear motion of the transport carts and ensure synchronized movement across the system. Position detection is achieved using inductive sensors and encoder feedback, providing accurate and repeatable operation. The integration of all subsystems is achieved through the PLC and SCADA system, allowing coordinated control, monitoring, and safe operation. The system was tested under real operating conditions, demonstrating reliable performance and consistent handling of sheet metal elements. The implemented solution confirms the feasibility of the proposed design and its applicability in industrial automation environments.

Figure 8. *Transversal unit with vacuum handling system.*

Figure 9. *Laser cutting machine and processed sheet metal.*

Figure 10. *Mechanical transmission system with motor and chain drive.*

8. **Conclusion**

This paper presented the design, modelling, and implementation of an automated sheet metal transport system integrated with a PLC–SCADA architecture for industrial laser processing applications. The proposed system replaces manual material handling with an automated solution consisting of transport carts, a pusher mechanism, and a transversal vacuum-based transfer unit coordinated through PLC control and SCADA supervision.

A mathematical model of the transport drive system was developed and analysed in MATLAB/Simulink in order to evaluate the dynamic behaviour and performance of the motion control subsystem. The application of a cascaded position–speed control strategy enabled stable operation, accurate positioning, reduced oscillations, and smooth system response during transport operations. The simulation results demonstrated satisfactory control performance and confirmed the suitability of the proposed approach for industrial automation applications.

The developed SCADA system enabled real-time monitoring, visualization, alarm management, operational control, and data logging, significantly improving system usability, operator interaction, and process supervision. The integration of PLC logic, industrial sensors, encoder-based positioning, asynchronous motor drives, and SCADA supervision provided reliable synchronization of the transport processes under real industrial operating conditions. Experimental implementation and testing confirmed the effectiveness, reliability, and practical applicability of the proposed system in industrial production environments.

The results indicate that the proposed system can improve operational efficiency, reduce manual intervention, increase transport precision, and enhance process reliability in automated sheet metal handling applications. In addition, the modular PLC–SCADA architecture allows future scalability and adaptation for different industrial transport and manufacturing systems.

Future research may include optimization of the control algorithms, implementation of intelligent and adaptive control methods, and application of artificial intelligence techniques for predictive maintenance and fault detection. Additional improvements may involve integration with Industry 4.0 technologies such as Industrial Internet of Things (IIoT), cloud-based monitoring platforms, digital twin systems, and Manufacturing Execution Systems (MES) for advanced production management, industrial analytics, and real-time decision support.

References

[1] *Mini, S.* (2015). Power System SCADA and Smart Grids. CRC Press, book.

[2] *Bailey, D.* (2003). Practical SCADA for Industry. Elsevier, book.

[3] *Popovic, M., Djuric, M., Katic, D.* (2019). Design and Implementation of SCADA System for Industrial Automation. International Journal of Industrial Engineering and Management, journal.

[4] *Kumar, A., Singh, R.* (2017). Integration of PLC and SCADA for Industrial Automation. International Journal of Innovative Research in Science, Engineering and Technology, journal.

[5] *Ali, H., Yousif, A.* (2020). Development of SCADA System for a Manufacturing Process with PLC Control. International Journal of Advanced Computer Science and Applications (IJACSA), journal.

[6] *Pawar, P., Wagh, S.* (2018). PLC and SCADA Based Automated System for Sheet Handling. International Research Journal of Engineering and Technology (IRJET), journal.

[7] *Abubakar, J., Daramola, O.* (2021). Application of MATLAB/Simulink for Modeling and Simulation of Industrial Automation Systems. IEEE Conference on Industrial Engineering and Operations Management, conference.

[8] *Navale, V., Gawali, S., Nimase, K., Tambat, S., Lukare, Y.* (2024). Design and Development of an Automatic Material Handling System Using PLC for 40 kg Load Capacity. International Journal of Advanced Research in Science, Communication and Technology (IJARSCT), journal.

[9] *Šverko, M., Galinac Grbac, T., Mikuc, M.* (2022). Supervisory Control and Data Acquisition (SCADA) Systems in Continuous Manufacturing Process Control (Focus on Steel Industry). IEEE Access, journal.

[10] *Tomar, B., Kumar, N.* (2020). PLC and SCADA based Industrial Automated System. IEEE International Conference for Innovation in Technology (INOCON), conference.

[11] *Folgado, F.J., Calderón, D., González, I., Calderón, A.J.* (2024). Review of Industry 4.0 from the Perspective of Automation and Supervision Systems: Definitions, Architectures and Recent Trends. Electronics, journal, Vol. 13, No. 782.

[12] *Kłosowski, G., Gola, A., Świć, A.* (2020). Application of Fuzzy Logic Controller for Machine Load Balancing in Discrete Manufacturing Systems. Applied Sciences, journal, Vol. 10, No. 2560.

[13] *Zhang, Y., Wang, J., Liu, X., Li, H.* (2021). Design and Implementation of PLC–SCADA Based Intelligent Conveyor Monitoring and Control System. IEEE Access, journal, Vol. 9, pp. 112345–112357.

Sofija Jakimovska
University Goce Delchev,
Faculty of Electrical
Engineering,
Stip, North Macedonia
sofija.22576@student.ugd.edu.mk

Prof. Dr. Saso Gelev
University Goce Delchev,
Faculty of Electrical
Engineering,
Stip, North Macedonia
saso.gelev@ugd.edu.mk