FACTA UNIVERSITATIS
Series: **Automatic Control and Robotics** Vol. 24, Nº 1, 2025, pp. 75 - 85
https://doi.org/10.22190/FUACR250404006L

Regular Paper

PHASE ANGLE CONTROL AND RPM MEASUREMENT OF UNIVERSAL MOTOR UTILIZING OF CAN BUS

UDC (621.313.14:621.3.018.12)

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Abstract. *This paper presents phase angle control and RPM measurement of a universal electric motor using a CAN interface. The system consists of two devices based on a microcontroller ATmega328P that are connected through a CAN bus for sending and receiving data for phase angle regulation and speed measurement. The system is implemented and checked in the laboratory using an oscilloscope and logic analyzer. Also, the obtained results and signal diagrams are presented as well.*

Key words: *CAN bus, universal motor, phase angle control.*

1. INTRODUCTION

Industrial machinery and home appliances use a large number of motors in their daily work. Home and industrial automation have changed significantly in the last ten years. In industrial applications and home automation, the electric motor is always a necessary part that is most often controlled. Motor speed control is necessary for all devices or systems to operate in precisely defined conditions. To control the speed of the motor in industrial applications have been usually used devices like thyristors [1]. In industrial and commercial appliances universal motors are widely employed in a variety of applications and household and industrial equipment also. The universal motor belongs to a group also known as AC commutator or AC series motors. It consists of a commutator and two carbon brushes, a rotor with a winding, and two concentrated excitation windings which are connected in

Received April 24, 2025 / Accepted September 03, 2025
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series and there are also cases where an excitation winding is connected in parallel with the armature commutation brush system [2,3]. The fundamental benefit of these motors is the capacity to run on a single-phase power source. An increase in use in various applications, including industrial and commercial, is evident [4]. The speed of the different types of motors is easily controlled thanks to the use of different regulation techniques. A controller with good efficiency is necessary for the control of the universal motor. Phase regulation and PWM regulation are common practices with universal motors and VFD regulation is for induction motors which enables high-speed control with high efficiency and high starting torque [5,6]. The most frequently used techniques are integral cycle control and phase angle control, which are also basic control techniques. In industrial heating and lighting control, these control techniques are effectively used. Electronic control of output voltage by changing firing times is the main advantage over integral cycle control. For a larger trigger angle, the main disadvantage is more harmonics in the output voltage. Single pulse width modulation is the most widely used method for controlling the speed of induction motors in the literature. Single pulse width modulation is inferior compared to phase angle control. Also, compared to the single pulse width modulation technique, the possibility of saving energy is slightly higher for phase control [7]. One of the key components of most industrial drives is the proper measurement of motor rotation speed. For electric motor engines measuring rotation is necessary to determine the amount of rotation of pieces of machinery and motor itself. This process is necessary, for monitoring the performance or control of the process of the motor. To estimate the motor's efficiency or its mechanical load the measurement of rotor speed is a simple and broadly used method in the industry. The tachometer is often mounted on the motor shaft to continuously monitor the speed. There are various techniques for measuring rotational speed, including contact and non-contact sensors, based on electromagnetic field fluctuations and conductive strips as well as those that rely on sensors based on optical reflection [8]. For control of the AC electric motor in the industry, often are used different types of protocols and interfaces for sending and receiving data about speed measurement, frequency, voltage, etc. The CAN protocol can also be effectively used for these purposes. For transmitting and receiving data from one ECU to another the CAN bus is utilized in this research. The proposed system reads the motor speed and also sends data about the phase angle for regulation of the speed of the electric motor on the other side [9].

2. METHODOLOGY

A method applied to AC circuits using the triac is phase angle control. Triacs are semiconductor devices that operate with AC voltage current with the ability to control high-level currents with small excitation currents and conduct current bidirectional. The control of the delay of the triggering angle in each half cycle of the triac simultaneously enables the control of the load power [10,11]. When triggered through the gate triac is a component that conducts in both directions. For the period t1, the angle of the sinusoidal voltage will be 45 degrees and the triac conduct only during the period, and therefore in that period we will have power that dissipated to the load. This power will, of course, be less than the maximum power when the triac misses the entire positive and negative half-cycle of the sine signal. A shorter conduction time will cause less power on the load, while a longer triac conduction time will allow more power to be dissipated on the load [12]. Fig 1. presents the principle of phase angle control in electrical circuits on a sine wave signal with an RMS of 230V.

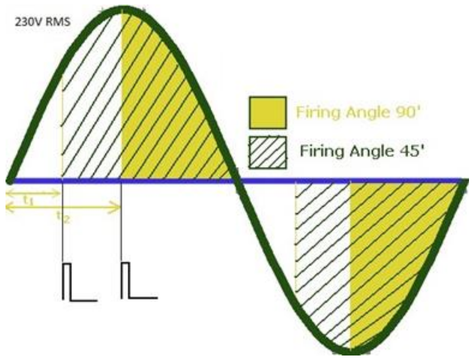

Fig. 1 Principle of phase angle regulation

By detecting the passage of the signal through zero, the Zero-cross method provides precise control of devices operating on alternating voltage. In electronics, it is used for various purposes, such as controlling the brightness of both incandescent and modern LED lamps, as well as controlling the speed of electric motors. Allowing us to properly control the devices operating on AC signals the zero-cross method detects the point where the AC signals pass through zero [13]. A typical circuit for phase angle control with triac and optoisolator which is usually applied in circuits with microcontrollers is shown in Fig. 2.

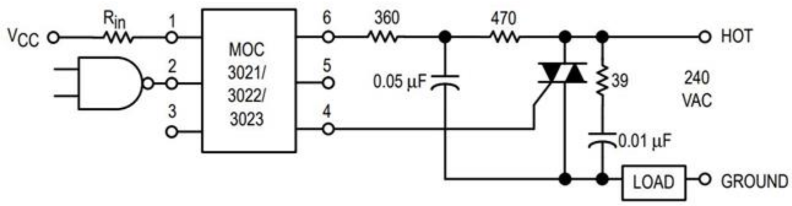

Fig. 2 Phase angle control circuit with triac and optoisolator

As with internal combustion engines and electric motors, the process of measuring rotation is intended to determine the amount of rotation of the machine. The quality of measuring the results of the initial or final rotation of the machine piece is also affected by motor rotation measurement results. To determine the quality of the motor, a necessary measuring instrument for measuring revolutions is necessary. The quality of the motor must be improved if the measuring instrument shows that the rotation of the machine starts to decrease. The rotation produced by the motor, i.e. RPM (Revolution Per Minute) can be determined using Equation 1.

$$RPM = \frac{F60}{P} \tag{1}$$

Where *RPM* is the rotation per minute (RPM), *F* is the frequency (Hz) and *P* is the pole or number of poles.

A tachometer is an instrument for measuring rotation. The alternative name for a tachometer is an RPM measuring tool [14]. A tachometer can be defined as a revolution counter because it generates a signal that expresses the level of rotational speed and shows the measured rotational speed in revolutions per minute (rpm). The principle of operation of revolution counters is mainly based on the measurement of the time interval between the measuring device and the body affected by the rotation or the measurement of the repetition of pulses generated by the rotation of the shaft. The fast movement of the shaft will result in a higher output voltage, that is, the signal amplitude will be directly proportional to the speed. Depending on the direction of rotation of the shaft, the output voltage will be positive or negative [15]. In this work, it is used an optical-type tachometer. Its internal structure is based on an infrared LED and phototransistor. Every intersection of the beam of light emitted by the infrared diode will produce a pulse because the state of the phototransistor will change. The output of the optocoupler is connected to the interrupt pin of the microcontroller and every change will be read and calculated. The optical type of tachometer photo-interrupter is shown in Fig. 3.

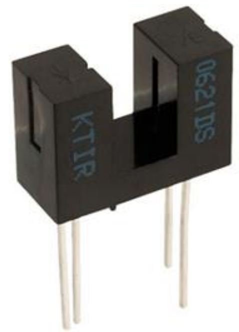

Fig. 3 Kingbright KTIR0621DS photointerrupter

3. CAN BUS PROTOCOL

CAN (Control Area Network) enables the communication between different components of the electronic system and the microcontroller without the use of a main computer. It is used in large machinery and automotive industry due to its strong reliability, good node expansion, and high real-time. This protocol can be used in different contexts and is based on messages. Its main purpose is to save copper and was originally designed for multiplexing conductors. The exchange of information and communication between ECUs is the main application of this protocol and it is one of the most widely used bus protocols. The CAN bus has high immunity to interference and fault tolerance due to the differential signals on the bus. Also, high signal speeds over twisted pair (twisted pair cable) are possible thanks to balanced differential signals on both lines that reduce noise superimposition. Interference is automatically canceled by balancing the differential signals. The signals on both signal lines are identical only in the opposite direction [16,17]. CAN bus has some similarities with the RS485 industrial standard interface such as a differential signal on the bus and immunity to noise and because of that advantage, it can be used also in industrial appliances as different protocols. Fig. 4 shows the connection of multiple ECUs on a CAN bus.

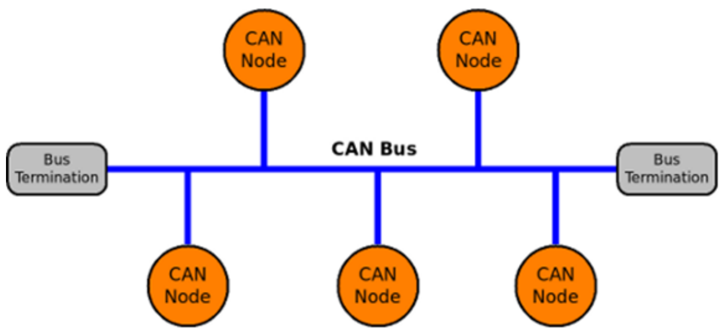

Fig. 4 Multiple ECUs connected on a CAN bus

4. PRACTICAL IMPLEMENTATION OF THE SYSTEM

For this research, a prototype of the system is developed. The prototype consists of two different nodes. Both nodes are based on an 8-bit microcontroller ATMega328P with a standalone CAN controller MCP2515 and they are both programmed and execute the predicted program [18,19]. CAN controller is used for the communication between them and the TJA1050 CAN transceiver [20]. The first node of this system is a control node and it has also 4 push buttons for turning on and off and for increasing and decreasing the firing phase angle of the triac. On this node are present values of the angle value and RPM of the induction motor. The second node has optoisolator MOC3021 which is used for triggering the triac BTA12 and optocupler H11A1 which is used for zero crossing detection. Also, this node does the RPM measurement of the electromotor and sends this information to the first node so in this situation there exists the control of electromotor. A block diagram of a system is shown in Fig. 5.

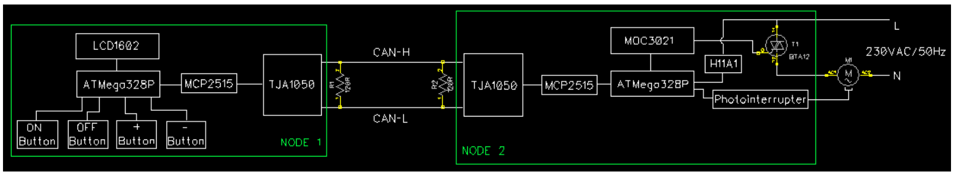

Fig. 5 Block diagram of a system

Both nodes are implemented on printed circuit boards and packaged in a universal plastic box for electronics. The power supply for the first node is realized through a cable that is used for CAN communication and it is 9V while the CAN node's operating voltage is 5V. The communication speed is 500kB/s which is enough for a 20m cable length. With lower speed, it is possible to use a cable of 500m or more depending on the application. Fig. 6 shows the practical implementation of the prototype.

Fig. 6 Practical implementation of the prototype

The electric motor that is used is a universal type. It is a low-power motor with a max power of 300W with 230VAC and its speed will be controlled by controlling phase angle and measurement of RPM [21]. For both microcontrollers in the circuit appropriate software is written. Node 1 sends a command for turning ON the motor and increasing and decreasing the value of the phase angle is already sent via CAN bus. At the same time message about the value of RPM was received. On the second node receiving command is done and the microcontroller turns on the triac via optocoupler MOC3021 with the received value of the phase angle. In this node zero crossing algorithm detection of zero for sinusoid to trigger the triac as precisely as possible is also implemented. Measuring of revolution per minute (RPM) is done by using a photointerrupter and interrupt pin of the microcontroller. In the microcontroller is also a part of the program that calculates the revolutions per minute. This information is sent back to node 1 and information is represented on the LCD1602 screen with an angle value. Fig. 7 shows simplified algorithms for both nodes on a CAN bus.

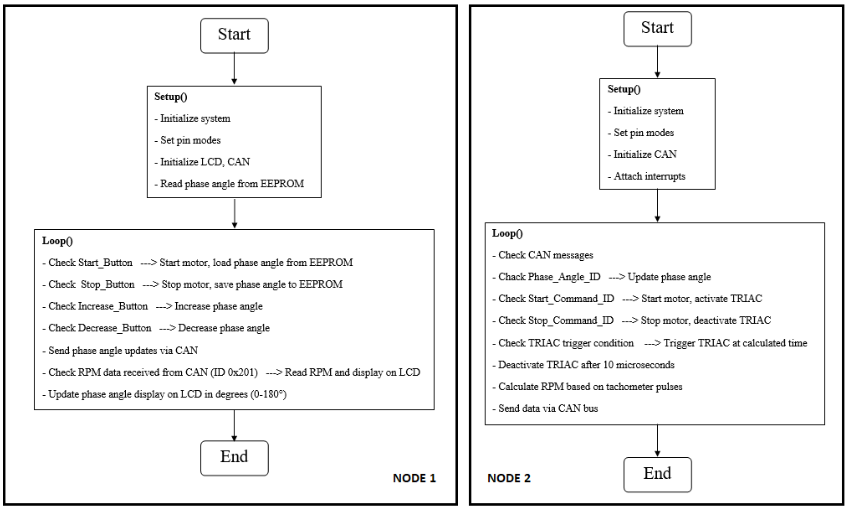

Fig. 7 Simplified algorithms for working of nodes on a CAN bus

5. Laboratory Work and Results

Connecting of the system is done in a laboratory using appropriate equipment. Node with a triac is connected with a motor and main power supply. The electric motor also has an X2 MKP capacitor with a capacitance of 0.1uF/280V and a resistor of 1.5MΩ which are used for filtering electromagnetic interference. Also, output voltage waveforms are visualized by using the USB oscilloscope Hantek and computer. Although it is possible to reduce the voltage for a safe connection of the oscilloscope probe, it is possible to use a voltage divider because the laptop does not have a connection to the ground and uses a battery. But for greater safety, a step-down transformer 230V/10.7V was used, which provides complete galvanic isolation between the oscilloscope probe and the mains voltage. In this way, a lower voltage is obtained that has no physical contact with the mains, and as such is suitable for further analysis. Also for this purpose, it is normal to use a differential probe, but this method is also fully applicable. The transformer will remove a harmonic from the output PWM signal. In situations when voltage measurement is necessary an isolation amplifier must be used. Fig. 8 presents the connection diagram of regulator, motor, transformer and probe.

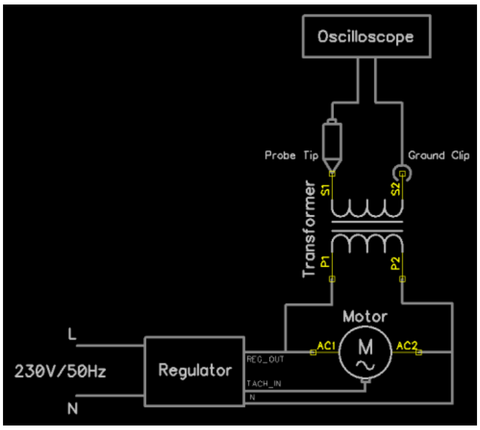

Fig. 8 Connection diagram of regulator, motor, transformer and probe

It must be considered that it is possible to control the speed of the electric motor on a full wave of sinusoidal voltage and for simple applications such as a fan this method works very well. The control node sends the value of the phase angle to the node with a triac and receives the value of rotation per minute from the second node. Fig. 9 presents the connection of the prototype of the system in laboratory.

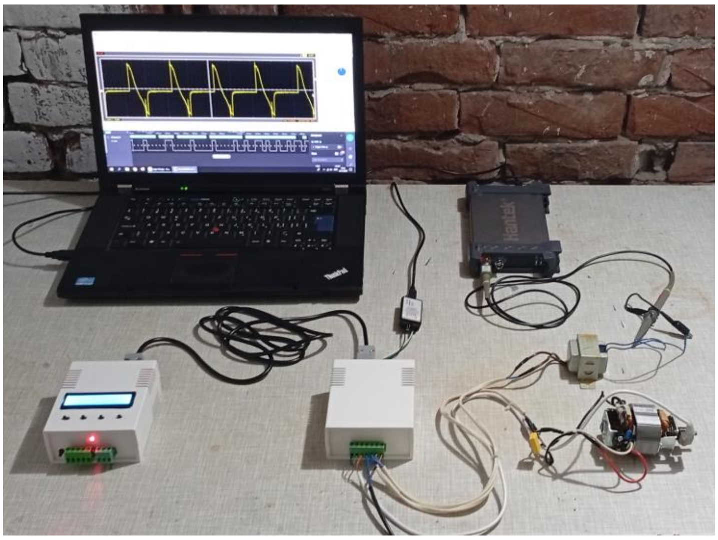

Fig. 9 Connection of the prototype of the system in laboratory

Communication between nodes is analyzed by using the Saleae 8-channel logic analyzer which is connected to the H and L lines of the CAN bus. Sending and receiving data is done by using messages with 3 values of ID. Messages are used for sending START command, STOP command, Phase angle value, and value of RPM. Communication began with sending the start command and data value 1 and this command turned on the motor. If it is necessary to stop the motor identifier is the same as 0x301 but the value of data is 0 and the motor has stopped. Fig. 10 and Fig. 11 present messages with START and STOP commands, respectively.

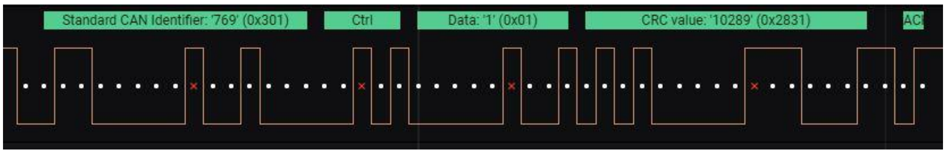

Fig. 10 A message with OD 0x301 and START command

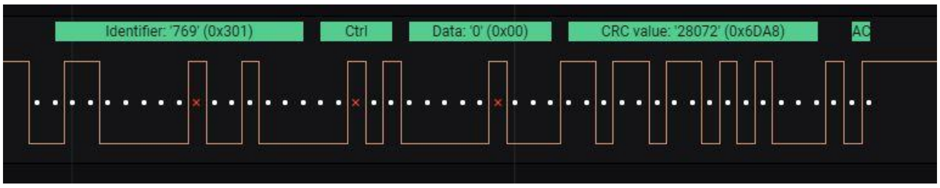

Fig. 11 A message with ID 0x301 and STOP command

The data with the value of phase angle is shown in Fig. 12. The identifier of the message is 0x101 and the data field is the value of the phase angle at that moment. This change of phase angle directly changes the time of firing the triac.

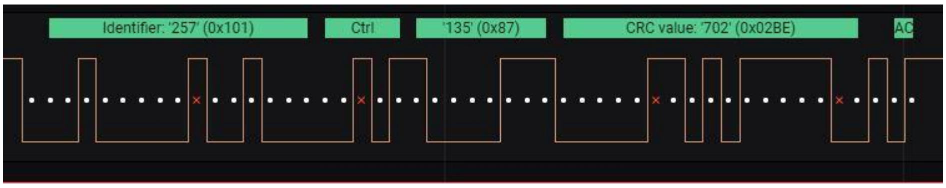

Fig. 12 A message with ID 0x101 and phase angle value

Fig. 13 presents the value of RPM which is received from node 2 that is done complete control on the motor and measuring of RPM.

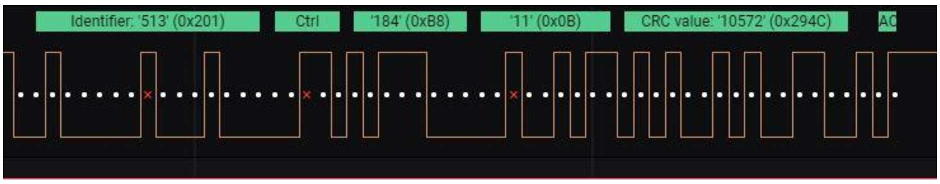

Fig. 13 A message with ID 0x201 and RPM value

Given that the universal electric motor represents a combined inductive-resistive consumer, with very small capacitive components there is a distortion of the appearance of the voltage and the appearance of transient processes in the circuit, as a result, the output voltage on the oscilloscope on the universal motor with increasing firing angle is shown in Fig. 14. The appearance of voltage fluctuations on the motor is common and expected due to its inductive nature. The presence of the capacitor does not affect the voltage on the motor because it is used for EMI.

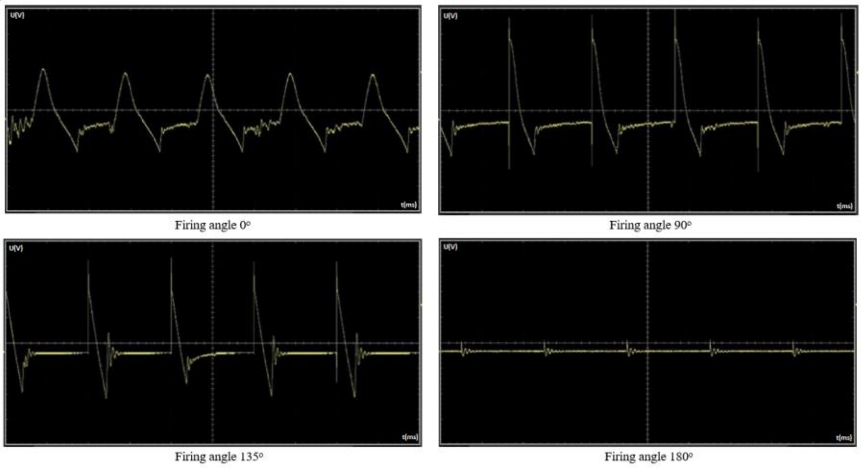

Fig. 14 The changing of voltage shapes on the motor with increasing firing angle

Using an optointerrupter with a microcontroller provides high precision for the measurement of RPM and it can be used for different types of motors. It is done with measurements with different firing angles, different trigger times and the results are shown in Table 1. Fig. 15 presents the dependence of the number of revolutions per minute on the phase angle. As the triac firing angle increases, the number of revolutions per minute decreases.

Table 1 Results of phase angle and RPM measurement

Meas. Num.	Phase Angle (°)	RPM
1.	0	20210
2.	30	19125
3.	45	18540
4.	50	17050
5.	63	16489
6.	77	14008
7.	84	12356
8.	90	10970
9.	100	9800
10.	120	8800
11.	142	5010
12.	150	2032
13.	165	351
14.	174	20
15.	180	0

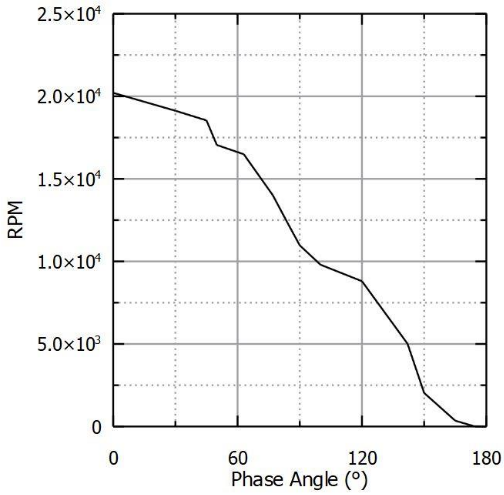

Fig. 15 Dependence of the number of revolutions per minute on the phase angle

6. CONCLUSION

The described method of controlling a universal motor is highly suitable for various applications. A typical use case for this circuit is in industrial fans or machinery that does not require precise control. While VFD regulation is a more advanced and accurate method for controlling induction motors in applications demanding high precision, the proposed approach offers a viable and cost-effective alternative for less demanding scenarios for universal motors. Additionally, the CAN bus protocol provides excellent flexibility, enabling long-distance communication with strong signal integrity and minimal noise or errors in the transmission. By utilizing a triac to adjust the phase angle, this method directly influences the voltage, current, and ultimately the power consumed by the load. This capability makes the approach relevant for further research and the development of systems aimed at monitoring and managing electrical parameters, particularly in food industry applications.

Acknowledgement: *This work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia [grant number 451-03-136/2025-03/200102].*

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