Position Control of the DC Motor for Autonomous Valet Parking using a Fuzzy Logic Controller

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Abstract: - This study suggests DC motor position control, an interesting control that most manufacturers are interested in. A number of applications use it, but autonomous valet parking is the most prominent. A fuzzy logic controller, a type of artificial intelligence controller, is used to implement this control. Prior to being implemented in LabVIEW software and QNET 2.0 DC motor hardware, it was first simulated in the MATLAB/SIMULINK environment. This controller's simulation feature helps get a favorable result without really harming the material. The same simulated outcome was obtained when this controller was experimented with on a QNET 2.0 DC motor using LabVIEW software. This environment is used to visualize the system's response or outcomes using virtual tools. The system responds quickly and effectively receives the order; there is no overshoot, peak time, or settling time.

Key-Words: - Fuzzy logic controller, Autonomous valet parking, QNET 2.0 DC motor, LabVIEW software, position control, membership function, fuzzification, defuzzification.

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1 Introduction

Because of their durability, affordability, and adaptability, DC motors are employed in a wide range of industries, including robotics and automotives. This is especially true in automated valet parking, where various sensors, including cameras, lidar, and fusion lidar, are used to gather data about the surroundings and destinations. Consequently, the DC motor is instructed using this processed data. Until the vehicle is fully parked, position control is necessary.

To guarantee correct parking, a variety of controls are utilized to regulate the car's position. Nonetheless, many enterprises and the industrial sector continue to use fuzzy logic controllers more frequently, [1].

A method based on fuzzy set theory developed in [2], [3] is the fuzzy logic controller. where a continuous membership function is used to categorize the items, [4].

The three essential phases that make up a fuzzy logic controller are fuzzification, which transforms a crisp input into membership functions that display a flow variable that represents the input values. A database or an expert creates rule bases, [5], [6], [7]. In order to obtain the proper output for controlling the DC motor, it presents them with a few possible outcomes and regulates the output to the incoming required control. The next step is defuzzification, which uses the Mamdani system and the center of area approach to convert a fuzzy signal into a crisp signal. Fuzzy logic controllers are becoming more and more popular because they can solve the non-linearity issue and work with dynamic systems with ease, [6].

It was challenging to increase efficiency since the fuzzy logic controller will restore the status that the DC motor had lost due to non-linearity, disturbance, etc, [8]. Due to advancements in artificial intelligence-based controllers, such as the one used in these work and artificial neural networks and genetic algorithm, DC motors have regained their significance in recent years, [9].

In order to improve system efficiency and reduce oscillations, this research proposes position control of DC motors using a fuzzy logic controller. The QNET 2.0 DC motor board was used to implement this work; an encoder on the board senses the position and controls the armature

voltage. The LabVIEW environment is used to turn on or off the motor and visualize the system's response. Here, the response will be visualized in the virtual instruments present in the environment, and the software will use certain toolkits and system-compatible drivers to control the system's on/off function. The first simulation, which was conducted in a MATLAB/SIMULINK environment utilizing a fuzzy logic block and a model of the DC motor utilized in the practical portion, yielded the results of the experiment.

2 DC Motor Model

An electrical device that transforms electrical energy into mechanical energy is a DC motor, [10]. Either the armature voltage [11] or a resistor connected in line with the circuit's armature voltage might be adjusted to control it. The first method will be used for control in this study. The motor's equations and equivalent scheme are discussed in Figure 1.

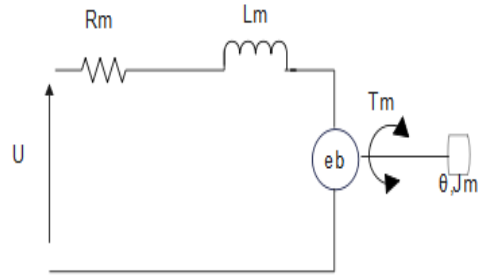

Fig. 1: Electromechanical model of DC motor

The electric equation of the armature voltage applying to the circuit:

$$u(t) = R_m.i(t) + L_m.\frac{di(t)}{dt} + e_b(t) \quad (1)$$

Where, the back electromagnetic force expressed by the following equation:

$$e_b(t) = K_m.w_m(t) \quad (2)$$

The mechanical equation is expressed by the second law of Newton as:

$$T_m(t) = T_R(t) + J_m.\frac{d^2\theta(t)}{dt} + B.\frac{d\theta(t)}{dt} \quad (3)$$

Where:

$$T_m(t) = \mathrm{K}.i(t) \quad (4)$$

And:

$$w(t) = \frac{d\theta(t)}{dt} \quad (5)$$

Applying Laplace transformation, these equations become:

The armature voltage presented by:

$$U(S) = R.I(S) + L.S.I(S) + E(S) \quad (6)$$

The back electromagnetic voltage becomes:

$$E(S) = K_m.\Omega(S) \quad (7)$$

The mechanical equations become:

$$T_m(S) = T_R(S) + (J.S + B)\Omega(S) \quad (8)$$

$$T_m(S) = \mathrm{K}.I(S) \quad (9)$$

Where U is the input voltage (V), Rm is the armature resistance (Ω), L_m is the armature self-inductance (H), E is the back electromagnetic force (EMF) (V), I is the armature current (A), Tm is the torque developed by the motor (N.m), θ is the angular position, w is the angular velocity(rad/s), Jm is the rotor inertia (Kg.m2), B is the equivalent coefficient of friction, Km is the emf constant (V.s/rad), K is the torque constant (N.m/A).

The block diagram that represents the DC motor using these equations is presented in Figure 2:

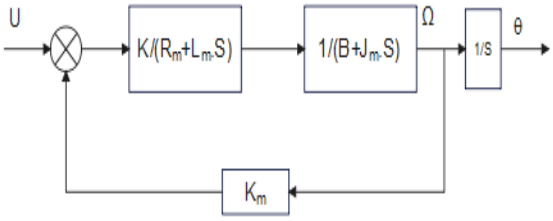

Fig. 2: DC motor Block diagram

From these equations and the block diagram, the transfer function is:

$$H(S) = \frac{\Omega(S)}{U(S)} = \frac{\mathrm{K}}{L.J_m.S^2 + (L.B + R.J_m).S + R.B + K.K_m} \quad (10)$$

3 Fuzzy Logic Controller Method

Fuzzy logic is a method for increasing the intelligence of a process, [12]. L.A. Zadeh invented it in 1965, using some state to describe the flow values. There are other options, such as artificial neural networks and evolutionary algorithms, but fuzzy logic is still easier for people to understand, [13], [14]. As shown in Figure 13, the fuzzy logic controller is made up of four major components, [15], [16], [17]. Fuzzification: the first block of the fuzzy controller that converts the crisp input into a fuzzy input, where this state is represented by membership functions with linguistic variables reflecting the range of input. Inference engine: a mechanism that uses various techniques expert from a human. Mamdani and Takagi-Sugeno are well-

known systems, [18]. They are based on membership functions, logical operators (and/or), and IF-THEN rules, [8]. Rule base: a group of linguistic statements helps to take the right decision to classify the input and give the right output. The form of writing for a MISO (multiple input single output) system is:
IF (fuzzy input 1) AND/OR (fuzzy input 2) THEN (Fuzzy output)
Defuzzification: is the step to produce a crisp output from a fuzzy input, [19]. The center of area gravity is the method used by this controller, [20].

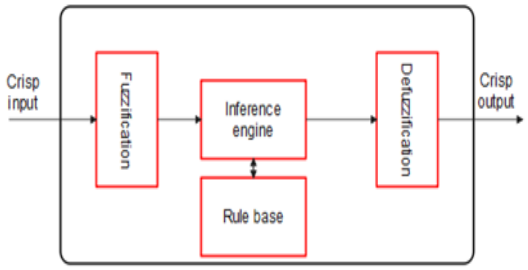

Fig. 3: Fuzzy logic controller blocks

This study uses MATLAB/SIMULINK to simulate position control using a fuzzy logic controller. LabVIEW software and a QNET 2.0 DC motor are then used to implement the simulation. The fuzzy Mamdani inference system was used. where the error change and the error are the inputs. The DC motor's armature voltage is the output. Rule bases try to determine the proper voltage instruction to the motor by examining the membership functions given by linguistic variables for the inputs and outputs. Seven membership functions are utilized for the inputs (error(e) and change of error (DE)) and output (voltage delivered to DC motor). They have a triangle shape, and Table 1 shows the linguistic variable:

Table 1. Linguistic variables

Linguistic variable	Abbreviation
Negative Big	NB
Negative Medium	NM
Negative Small	NS
Zero	Z
Positive Small	PS
Positive Medium	PM
Positive Big	PB

This triangular membership functions are divided using step value rule and by precision of the interval or range of each input and output as the Figure 4, Figure 5 and Figure 6 shown:

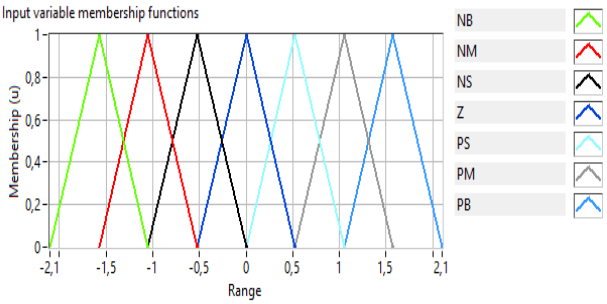

Fig. 4: Error membership functions

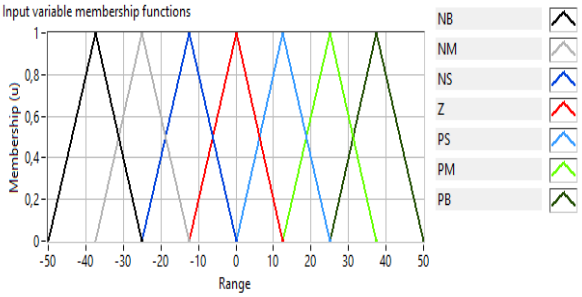

Fig. 5: Change of error membership functions

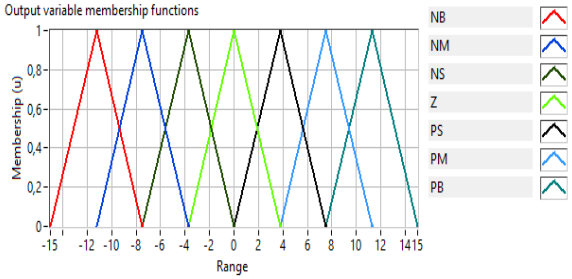

Fig. 6: Armature voltage membership functions

From the number of input and output membership functions. There will be 49 rule bases, with 7 membership functions for each input and output. They are stated using the IF-THEN formula. Table 2 resume the rule bases.

Table 2. Rules base

e/DE	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

They are expressed by this instruction shown in Figure 7:

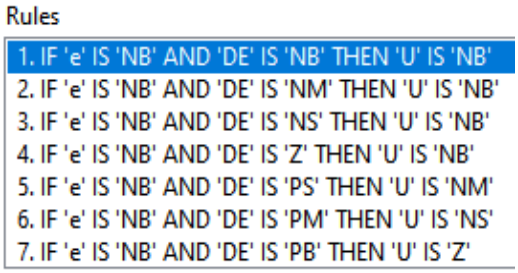

Fig. 7: Rules base formula in LabVIEW software

These rules are visualized in the test system by a 3-dimension surface as the Figure 8 shows:

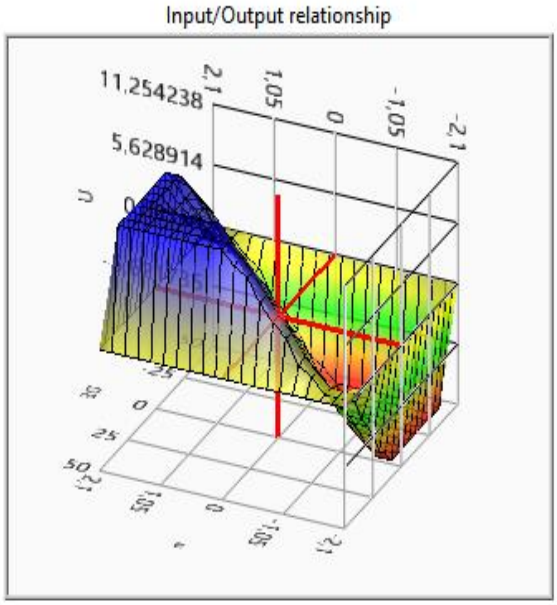

Fig. 8: Test of rules base using 3D surface (e/DE and U)

The position of the DC motor will be regulated by this theory and these blocks of the fuzzy logic controller. Before that, the QNET 2.0 DC motor is bump tested to determine the transfer function that will be used to represent it. This test was carried out utilizing hardware and LabVIEW software. The transfer function was discovered by giving a step command to the motor of first order, with steady-state gain K=29 rad/(v.s) and time constant of 0.17s. The DC motor had a second-order transfer function, as shown in the first work, but due to its small value, the armature self-inductance was eliminated in this work.

4 Simulation and Experimental Results

After testing the DC motor in MATLAB/SIMULINK environment, LabVIEW software is used to realize it using a QNET 2.0 DC motor.

4.1 DC Motor Position Control Simulation using MATLAB/SIMULINK Environment

The MATLAB/SIMULINK environment was used to develop a DC motor model with a fuzzy logic controller, as shown in Figure 9. The fuzzy logic controller's inputs are where the anticipated position and the actual position are compared to produce the error and error change. It gives the DC motor the right output, or the right armature voltage, so that it can deliver the right position.

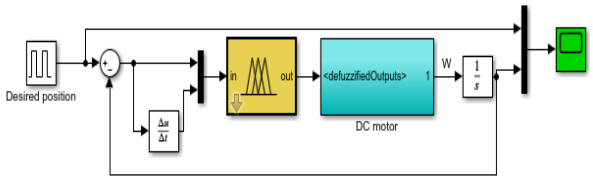

Fig. 9: Diagram used in MATLAB/SIMULINK simulation

As seen in Figure 10, the required position control fluctuated between 0 and 2 radians. The response of a DC motor following regulation with a fuzzy logic controller is shown in Figure 11.

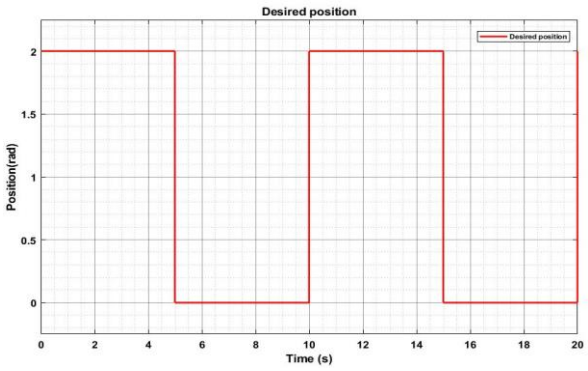

Fig. 10: Selected position profile of fuzzy logic controller validation

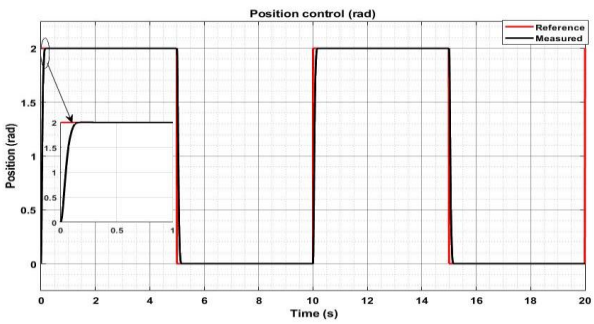

Fig. 11: Position response of DC motor for 0 rad and 2 rad

4.2 Implementation of Fuzzy Logic Controller using QNET 2.0 DC Motor

This part validates the position control performed by the simulation in a MATLAB/SIMULINK environment using LabVIEW software and a QNET 2.0 DC motor.

A block design utilizing the fuzzy logic discussed in the previous section and the toolkits and drivers of the QNET 2.0 DC motor is depicted in Figure 12. The experiment uses fuzzy logic rule bases that are studied in simulation using MATLAB/SIMULINK, as well as the same position control command of a DC motor and membership functions. As demonstrated in LabVIEW using the virtual instrument, the result is either the same in reality as seen in Figure 13 and Figure 14. The white trace in the motor's inertia is used in Figure 15 and Figure 16 to illustrate the change in DC motor position, confirming the outcomes of the orders 0 and 2 radians.

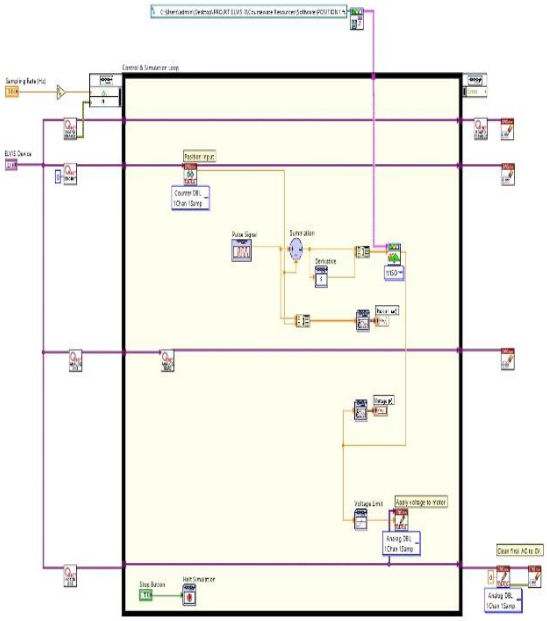

Fig. 12: LabVIEW block diagram used for controlling DC motor

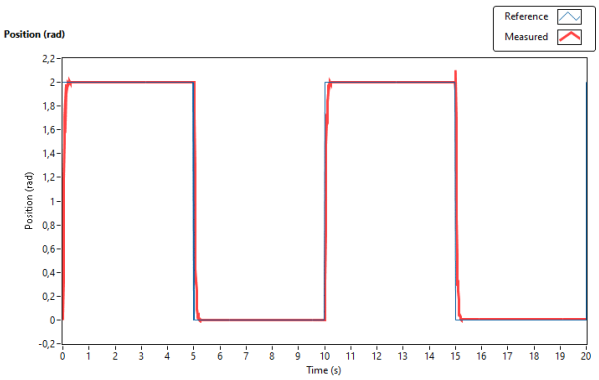

Fig. 13: Position response of QNET 2.0 DC motor for 0 radian and 2 radian using virtual instruments

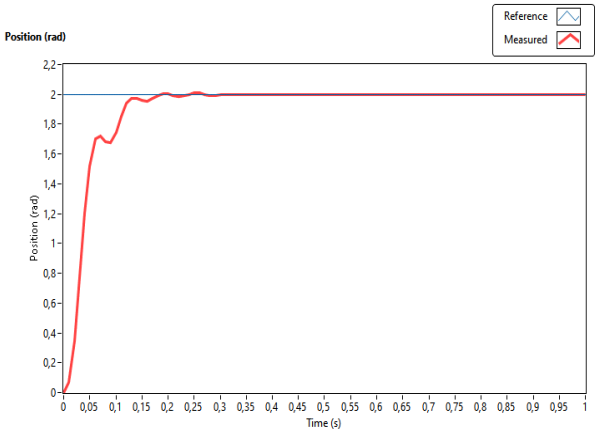

Fig. 14: Zoom in on the first step command of the position response using QNET 2.0 DC motor for 2 radians

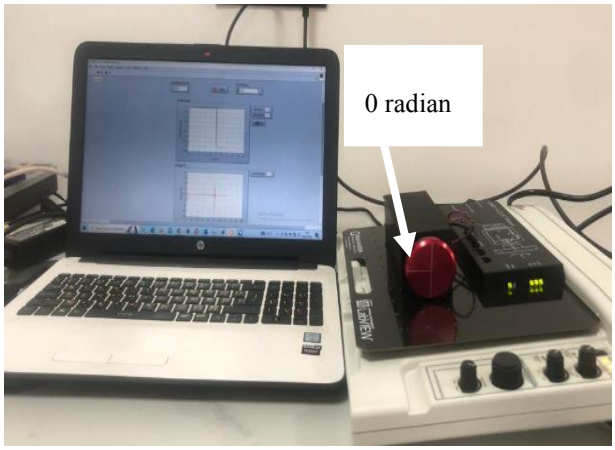

Fig. 15: Experimental position response of QNET 2.0 DC motor for 0 radian

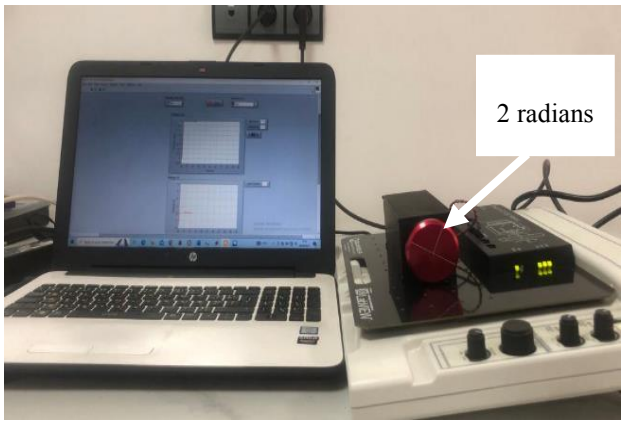

Fig. 16: Experimental position response of QNET 2.0 DC motor for 2 radians

The simulation results (Figure 11) demonstrate that the fuzzy logic controller enhances system reliability, achieving a response time of 0.2 seconds for 0 and 2 radian commands while closely following the reference. This is further validated by the experimental results shown in Figure 13.

According to Figure 11 (simulation) and Figure 14 (experiment), the control strategy is effective, as the system responds within 0.2 seconds to a 2-radian instruction without overshoot, peak time, or settling time, exhibiting only a minimal rise time.

In our application, sensors detect the region for autonomous valet parking, generating the necessary command. The fuzzy logic controller determines the appropriate voltage for the DC motor, ensuring accurate positioning. The system's reliability is confirmed in Figure 17, where various commands result in rapid and precise responses.

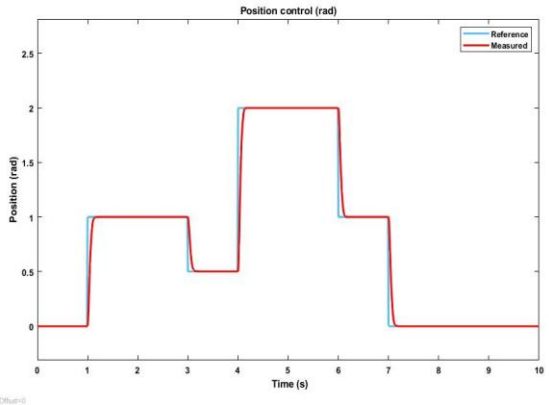

Fig. 17: Performance validation of fuzzy logic controller for different positions

4.3 Comparison with other Works

In [21], the authors found that the settling time using the optimized ACO algorithm based on a PID controller is 2.68 s, with no overshoot and no peak time. In [22], the authors use the optimized PSO algorithm based on a PID controller, they found that the settling time is 0.22 s, with no overshoot and no peak time. In comparison to our work, the FLC controller gives a better response where there is no overshoot and no peak time, only a small settling time of 0.2 s. To summarize, the controller employed in this paper is better due to the shorter settling times in both the' simulation and experimentation.

5 Conclusion

This study aims to regulate the position of a DC motor, commonly used in autonomous valet parking systems, by leveraging the advantages of a fuzzy logic controller. LabVIEW software is employed to visualize the controller's response with the QNET 2.0 DC motor and highlight its key role.

As previously demonstrated, this controller performs exceptionally well, eliminating overshoot and peak values while achieving precise control in a short time. Consequently, the fuzzy logic controller enhances system performance and is gaining popularity due to its effectiveness in dynamic and nonlinear systems.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Meriem Megrini, Ahmed Gaga carried out the simulation and implemented the the contributions in both environement MATLAB/SIMULINK and LabVIEW.
- Youness Mehdaoui has supervised the work.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.