AUIQ Technical Engineering Science

Volume 1 | Issue 1 Article 5

2024

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Recommended Citation

Hasan, Adnan Hussein and Saad, Mohammed Ayad (2024) "Control of a Robotic Leg Based on an Adaptive Optimized Fuzzy Algorithm," *AUIQ Technical Engineering Science*: Vol. 1: Iss. 1, Article 5.
DOI: https://doi.org/10.70645/3078-3437.1004

AUIQ TECHNICAL ENGINEERING SCIENCE 2024;1:49–55

ORIGINAL STUDY

Control of a Robotic Leg Based on an Adaptive Optimized Fuzzy Algorithm

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ABSTRACT

The goal of our investigation is to create a way of directing a robotic limb that is based on an adaptive optimum fuzzy algorithm, as is clear from the study's title. To create an adaptive fuzzy controller for a robotic limb is the goal of this project. By joining the robotic leg to the human foot, it is possible to increase load-bearing capacity and make up for limitations brought on by injury, ageing, etc. Consider a 3R planar open chain for the leg. Rotating actuators supplied by a fundamental control system are used to regulate the robot joints' motion in order to counteract external stresses and provide the required torque for steady motion. The control system generates control commands using fuzzy logic and fuzzy rules. The fuzzy rules parameters must be modified based on the external loads and conditions that are perturbing in order to achieve the best energy consumption performance. As a result, fuzzy rules are variable-parameter adaptive functions. A method based on the honey bee algorithm (BA) is used to change the settings. The stated control system should activate joint actuators in the presence of disturbance loads to maintain steady and accurate motion.

Keywords: Robotic leg, Adaptive optimized fuzzy algorithm

1. Introduction

Robot legs are mechanical limbs with the same capabilities as a human leg. They can be electrically or mechanically operated, and doctors must reroute nerves to contract the thigh muscles [1]. Sensors detect electrical pulses generated by re-innervated muscle contraction and existing thigh muscle [2]. A robotic leg attaches to an individual who has had a lower extremity amputation [3]. Doctors and technicians measure the remaining limb structure and prosthesis to fit the robotic leg. Sensors are embedded in the robotic leg to measure electrical activity created by re-innervated muscle contraction and existing thigh muscle [4, 5].

Robotic legs have been a major area of study and development in recent years [6]. They can be used on patients who have had amputation surgery due to trauma or illness, as well as in the treatment of military combat injuries [7, 8]. MIT is striving to develop a "bionic" robotic limb that can function as if it had biological muscles [9]. Fuzzy logic is a method of computation based on "degrees of truth" as opposed to the standard "true or false" (1 or 0) Boolean logic used by modern computers [6, 10]. In the 1960s, Lotfi Zadeh of the University of California, Berkeley proposed the concept of fuzzy logic for the first time. The following Fig. 1 explains what fuzzy logic means [7, 11].

Fuzzy logic is a technique to process variables that allows for the processing of numerous potential truth values through the same variable [13, 14]. It aims to answer issues by employing an open, imperfect spectrum of facts and heuristics, which allows for a

Received 5 June 2024; accepted 24 July 2024.
Available online 23 August 2024

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https://doi.org/10.70645/3078-3437.1004

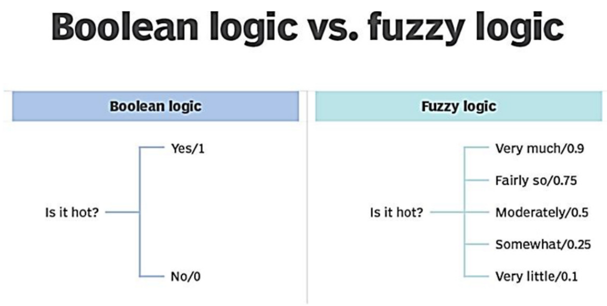

Fig. 1. Fuzzy logic means [12].

variety of accurate conclusions [15]. This research aims to investigate the control of a robotic leg based on a fuzzy algorithm, which is invented by modern industry and medicine engineering [16].

The concept of fuzzy logic was introduced by Lotfi Zadeh in the 1960s, and it has since been applied in various fields including control systems for robotic limbs [4, 17]. Fuzzy logic controllers can handle the uncertainties and variations in the inputs, making them well-suited for adaptive control systems that must operate under dynamic conditions [18, 19]. This research aims to develop an adaptive fuzzy controller for a robotic leg [20], designed to increase load-bearing capacity and compensate for limitations due to injury, aging, or other factors [21]. The robotic leg system will be modeled as a 3R planar open chain [22, 23], with rotating actuators controlled by a fundamental control system to manage joint movements [11]. The control commands are generated using fuzzy logic and fuzzy rules [4], which adapt based on external loads and perturbations to optimize energy consumption and performance [24, 25].

To enhance the adaptability and efficiency of the control system, a method based on the honey bee algorithm (BA) will be employed to adjust the fuzzy rule parameters [21, 26]. This adaptive approach ensures that the joint actuators respond accurately and steadily to disturbances, maintaining stable motion and providing the necessary torque for various activities [27, 28].

In summary, the development of a robotic leg controlled by an adaptive optimized fuzzy algorithm holds significant potential for improving prosthetic technology [29, 30]. By leveraging advanced control strategies and adaptive mechanisms, this research seeks to create more effective and reliable robotic limbs that enhance the mobility and independence of users [31]

2. Hypothses

Based on the information in our research proposal and the hypothesis of our current study, we may list the following:

1. The hip, knee, and ankle are three movable joints that make up the open kinematic chain that is the leg.
2. There is a planar leg.
3. The control system must offer the necessary torque to overcome outside loads.
4. Human motion occurs in a plane

3. Overview of the system

Robb William Colbrunn in 2001 worked on the design and control of a robotic leg. To accurately mimic the movement of a leg on a mobile robot, the leg was designed to be able to switch between a swinging and a standing position. The control method needed three different feedback signals to be sent from each joint: angle of each tensile actuator's joint and the amount of force it produces. Potentiometers and strain gauges-based force transducers were built specifically for this purpose and installed on the leg. Sensor signals were sent to a computer, which was responsible for making the A/D and control choices.

The completion of the control software resulted in the transmission of signals on DIO lines, which were then linked to optical relays. The relays sent the commands that caused the valves to open and close, which in turn transported air into and out of the actuators, which in turn moved the leg.

An overview of the hardware system is presented in Fig. 2.

4. Design of robot leg

The leg was designed to have proportions like those of a cockroach (Fig. 3), but its action was nothing like that of a cockroach. It had four degrees of freedom, including the unactuated linear motion of the trolley on the track, the vertical linear motion caused by the air cylinder, the rotational motion of the hip [9], and the rotational motion of the knee.

A 50-conductor ribbon cable with twisted pairs linked the leg to the controller, and a 100 gallon tank was linked to a 10mm umbilical connection that supplied the leg with air (Fig. 4). The four degrees of freedom included the unactuated linear motion of the trolley on the track, the vertical linear motion caused

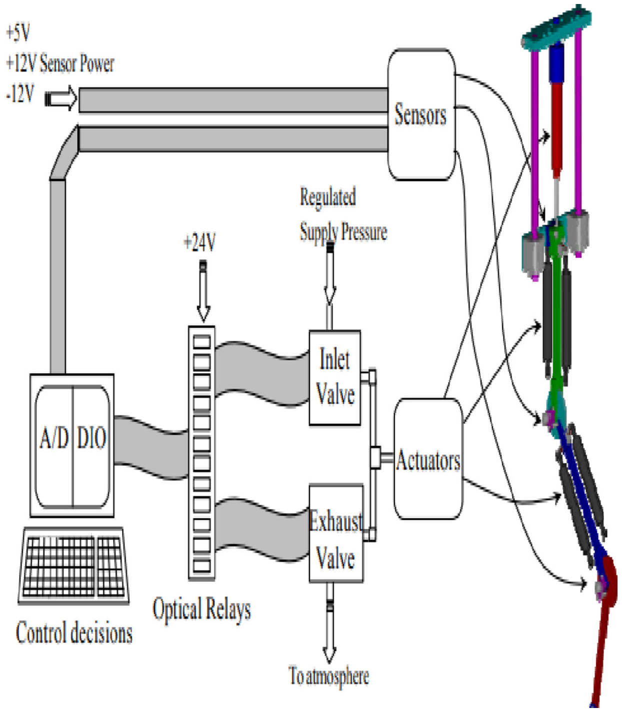

Fig. 2. Described above in system overview of the robot hardware.

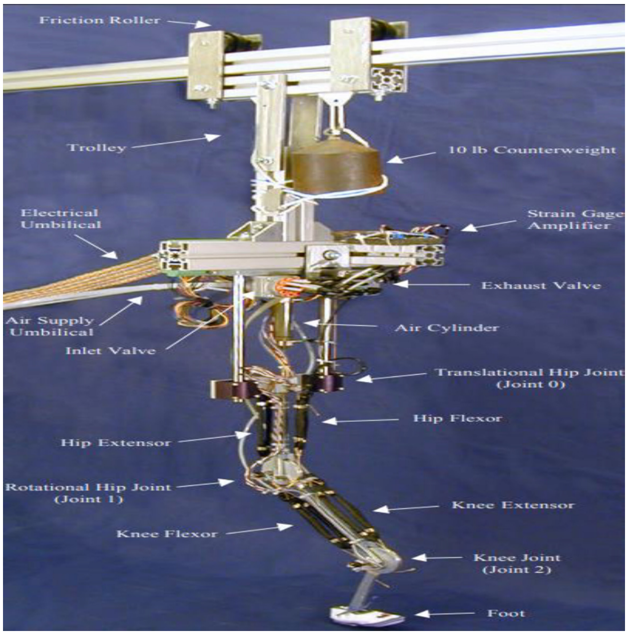

Fig. 3. A labeled image of the finished leg.

by the air cylinder, the rotational motion of the hip, and the rotational motion of the knee [31].

With the exception of the air umbilical, all of the piping on the robot was constructed out of 5/32" nylon tubing coupled with fast detach Legris fittings. A CAD schematic and an image showing a close-up of the hip translational joint are presented in Fig. 5.

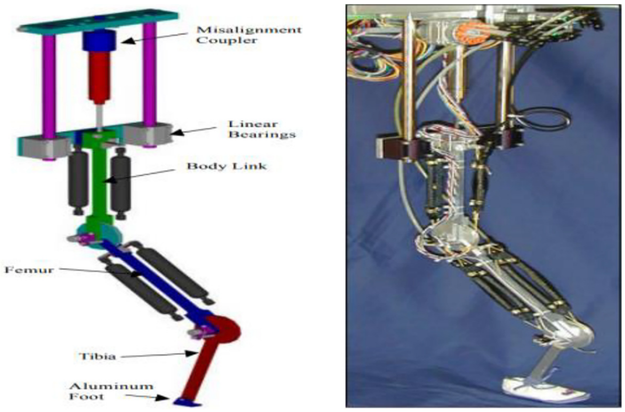

Fig. 4. Depicts the leg from the same vantage point.

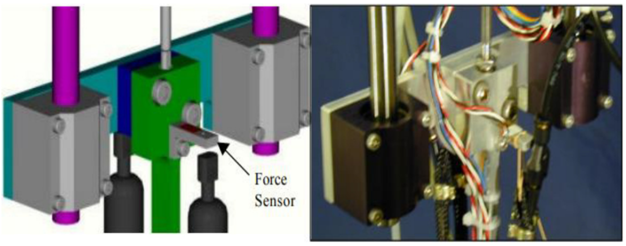

Fig. 5. A close-up of the hip translational joint.

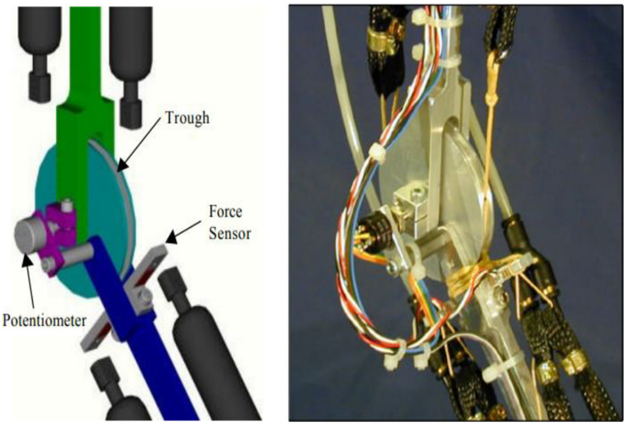

Fig. 6. The hip rotational joint is depicted in both CAD design and picture.

As it is obvious at the following figure, the hip rotational joint is depicted in both CAD design and picture. Take note of the machined trough that has been created for the tendon, as well as the packing of the angle and force sensors (Fig. 6).

The design of a walking robot was based on a pair of braided pneumatic actuators that worked in opposition to one another, providing a joint with changeable stiffness. Watson et al. (1998) demonstrated that antagonistic muscles are activated shortly before the foot plant, suggesting that maintaining a healthy level

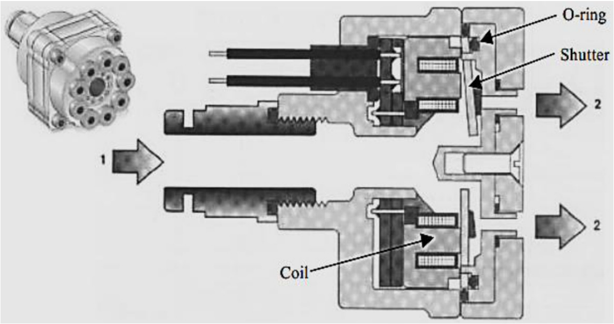

Fig. 7. Channel, 2-way valve with a speed-up arrangement was used as the inlet valve.

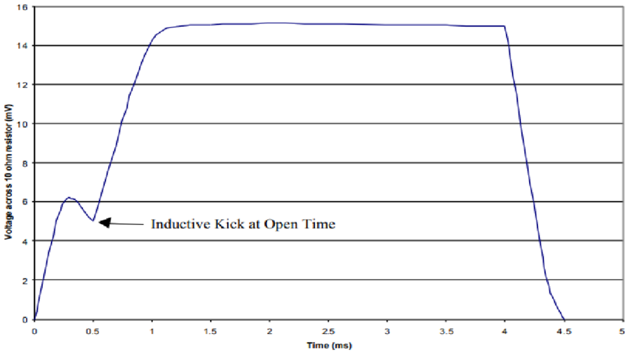

Fig. 8. Current vs. time for inlet valve 125 Hz square wave at 50% duty cycle.

of joint stiffness could have positive effects on walking. To meet the requirements set by the cam design with a 2" diameter, it was decided to double the number of actuators in each joint, resulting in a maximum force of 30 lbs. The actuators had a range of motion of 1.4 inches, which was enough for accomplishing the intended leg excursions.

The actuator free length was adjusted to the optimal value of 3.15 inches, which allowed for half the range of motion. Markers were made on the tendon and the tendons were knotted securely around the distal portions to adjust the resting angle. The mechanical drawings for the leg are included in Appendix C.

5. The valves

Matrix S.P.A., located in Italy, was the company that produced the solenoid valves. An 850 series, 9 channel, 2-way valve with a speed-up arrangement was used as the inlet valve. As we can see here the Fig. 7 can better illustrate the valves to be used in a robotic leg.

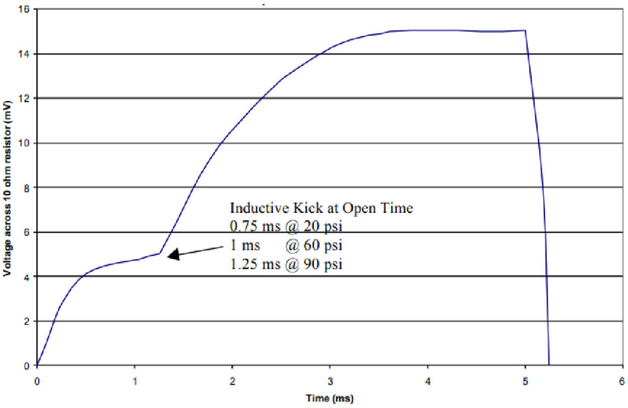

Fig. 9. A graph of the exhaust valve's current versus time.

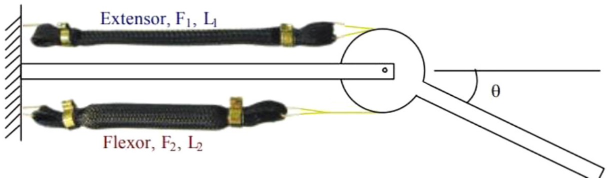

Fig. 10. The diagram shown In order to assist in the teaching of the control theory.

This valve was built to operate in a speed-up mode, but after the spring was taken out, the reaction times could no longer be relied upon as accurate. Tests were carried out to ascertain the actual speed of the valves and the highest possible frequency at which they might function. An oscilloscope was used to analyze the voltage drop across the resistance. A plot of the current vs. the amount of time for the inlet valve was shown in Fig. 8. The supply pressure was set at 100 psi and the command signal was a square wave with a duty cycle of 50% and a PWM frequency of 125 Hz.

The shutter was opened in 0.5 milliseconds, but there was no correlation between supply pressure and open time. The only conclusion was that the current had left the system around 0.5 milliseconds after the valve was instructed to close. Fig. 9 showed that the valve had a fast reaction time and the audible maximum frequency was higher than 400 Hz. A 100Hz PWM signal with a 50% duty cycle was used to change the supply pressure.

6. Control of a robotic leg

This thesis focuses on finding ways to run a robot with less air. Two 2-way valves were installed in place of a single 3-way valve to allow air to be captured even when it is not necessary to activate the actuator. A control system was designed that could only open one valve at a time, changing the concept of control from that of regulating air pressure to that of controlling air mass. The system of mass control was used to move air mass towards and away from the actuator.

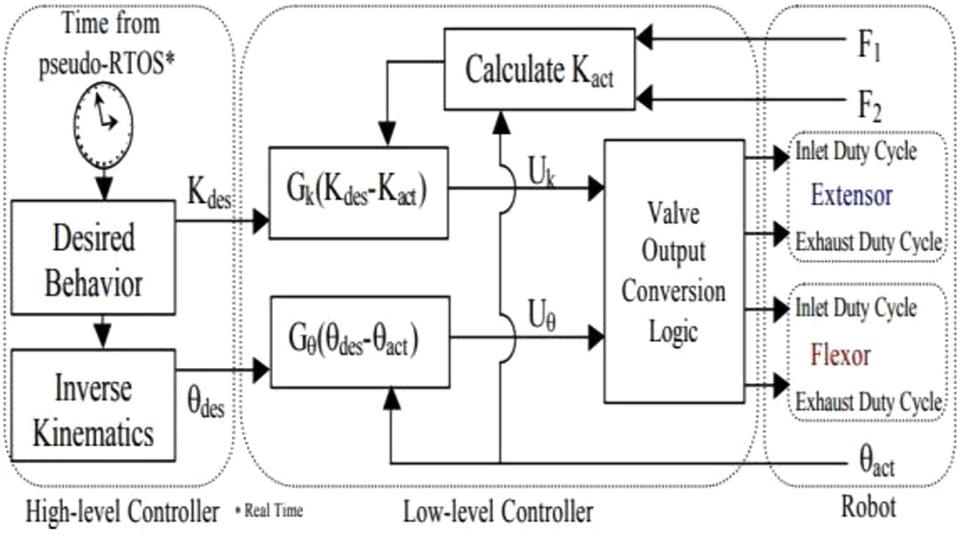

Fig. 11. A block schematic of the control algorithm.

Two controls were used: a high-level controller responsible for generating the trajectory, carrying out inverse kinematics, and making modulations on control gains. A low-level controller was responsible for regulating the system depending on the intended values passed down from the higher-level controller. Two control rules were layered on top of one another to reduce the amount of oxygen breathed in. The diagram shown in Fig. 10 is a schematic of a joint.

Actuators for the flexor and extensor muscles were given the numbers 1 and 2, respectively. When the flexor muscle was contracted, there was a rise in q. A block schematic of the control algorithm may be found in Fig. 11.

7. Results and discussion

The project's intended outcome was a robotic leg that could walk thanks to braided pneumatic actuators acting as the main movers. As a result, a desired trajectory was built in order to advise the leg on how to walk. However, the robots' range of motion must first be determined in order to build the trajectory. In the chapter before, a theoretical joint range of motion was discussed. On the other side, when there was no force exerted on the actuator, that is when the length of the actuator was at its shortest. Additionally, the impact of gravity on the combined mass of the leg pieces was not taken into account. As a result, utilising an antagonistic design, the full range of motion that an actuator was capable of was not possible. The following Table 1 lists the precise joint excursion limitations.

Table 1. The actual joint excursion limits.

Joint	Maximum extension angle	Relaxed joint angle	Maximum flexion angle	Range of motion
Hip	249°	278°	307°	57°
Knee	343°	314°	289°	54°

Table 2. Showing D–H parameters.

Linkage j	$\alpha_i/^\circ$	d_i/m	a_i/m	$\theta_i/^\circ$
1	90	0	0	−35–45
2	0	0	$L_2 = 0.103$	74–168
3	0	0	$L_3 = 0.141$	49–148

Depending on the weight of the parts and how they were assembled, Table 1 indicates that the actual maximum range of motion was probably around 60 degrees. The lack of accuracy with which the actuator free lengths were guaranteed during assembly affected the range of motion even further. This explains why the hip joint, which was connected to more of the leg mass than the knee joint, which was just connected to the tibia, had a larger excursion (Fig. 12).

According to the Denavit–Hartenberg convention, the kinematic model of the robot is established in Fig. 13 that can be illustrated as follows.

The hexapod robot's leg construction is optimized in terms of available area and energy usage. The below Table 2 displays the Denavit–Hartenberg parameters.

8. Conclusion

This study proposes an enhanced compliance control technique for a hexapod robot's impact minimization and steady walking in varied situations. Adaptive

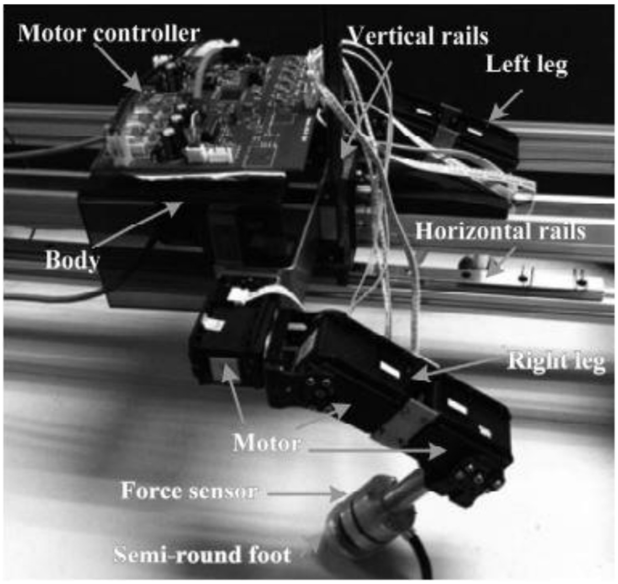

Fig. 12. Test rig for compliance control.

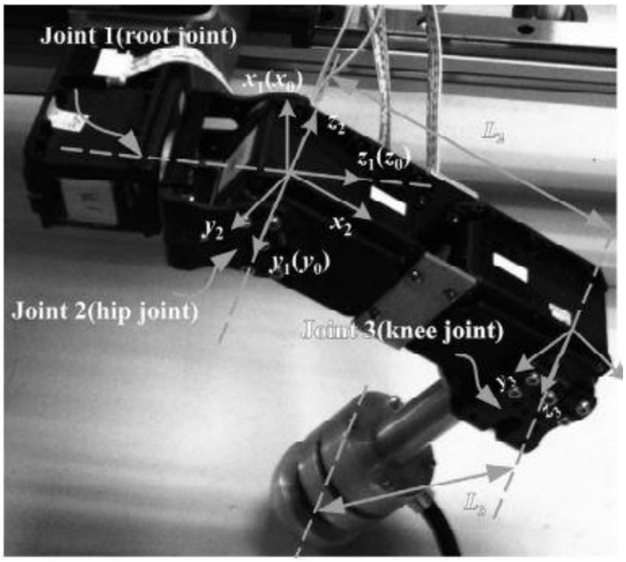

Fig. 13. Reference frames of the leg.

control settings are modified based on the environment. By modifying the settings, the fuzzy controller enables a quicker convergence speed to be maintained in any environment and a more balanced foot force controlling pace of the legs, so ensuring steady walking on unknown difficult terrain. With a series of studies conducted under varying conditions, disturbance levels, and body height, both techniques are evaluated. The findings indicate that the enhanced version is capable of achieving a quick reaction even in contexts with increased complexity. Despite the fact that this article just performs a basic authentication on compliance control, it is nevertheless able to successfully show both the practicability and efficiency of the suggested technique. The relevance of the compliance control that was applied to the walking robot is also demonstrated here. As a result, this aspect of the research is still highly crucial for the hexapod robot's ability to walk autonomously outside of the laboratory setting.

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