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Design and Development of a Low-Cost Quadruped Robot for Educational Robotics Applications

Trupti D. Bahirat[1], Kshitija R. Bhadake[1], Vishal P. Bargal[1], Vaibhav E. Bendre[1], Naveen Kumar[2]*

Abstract

The locomotion of the quadruped robots resembles that of four-legged animals and can be used on surfaces that wheeled robots cannot navigate. The paper is a design and development report on a low-cost quadruped robot that has been designed to be used in educational and experimental robotics. The robot is a lightweight and modular robotic system consisting of a combination of mechanical design, embedded control, and wireless communication. The actuation of the joint is carried out by the use of servo motors, and the control of motion is carried out by an Arduino Nano microcontroller. The mechanical design is made with lightweight 3D-printed parts such as coxa, femur and tibia links. To provide smartphone control and a Bluetooth interface, a Bluetooth module is used, and the voltage is steadied by a buck converter to supply the electronic parts. To provide a stable locomotion and balance a crawl gait algorithm is used. Through experimental testing, it has been proved that the robot is capable of walking and turning on flat surfaces with a reasonable degree of stability. It has been shown through the developed system that a useful quadruped robot could be built with relatively low cost and readily available parts and, therefore, could be used in robotics education as well as introductory research.

Keywords: Arduino nano, educational robotics, gait algorithm, quadruped robot, robotic locomotion, servo motors

INTRODUCTION

The study of robotics is more and more concentrated on bio-inspired locomotion systems capable of acting within complex, unstructured environments. Quadruped robots are designed to move using four legs; they are more stable and offer greater adaptability than wheeled or tracked robots. These robots can traverse uneven surfaces, climb small obstacles, and maintain balance on surfaces that conventional robots find hard to negotiate. They are suitable for areas, such as search and rescue, inspection, dangerous exploration, and robotics research due to such capabilities [1].

Quadruped robots utilize the movements of animals like dogs and horses that exhibit effective and synchronized movement over various landscapes. Engineers are trying to model these motions with mechanical connections, actuators, and control programs which synchronize the movement of several joints. Critical areas of the quadruped robot design are gait generation, balance control and optimization of the structure to attain smooth locomotion [2].

***Author for Correspondence**
Naveen Kumar
E-mail: kumarnaveenmkcoe@sanjivani.org.in

[1]Students, Department of Mechatronics Engineering, Sanjivani College of Engineering, Kopargaon, Maharashtra, India
[2]Assistant Professor, Department of Mechatronics Engineering, Sanjivani College of Engineering, Kopargaon, Maharashtra, India

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More advanced robotic systems produced by research laboratories have advanced actuators, real-time sensors and powerful control systems, which allow dynamic and adaptive locomotion. Nevertheless, these systems are usually complicated and costly to implement in learning institutions. Thus, scaled-down quadruped robots based on microcontrollers and servo motors have been popular in academic schools and student projects [3].

In this paper, the design and creation of a low-cost quadruped robot made out of readily available materials, such as servo motors, Arduino Nano microcontroller, and 3D-printed mechanical components are presented. The objective is the creation of a lightweight robotic platform which can walk with steady behavior by simple gait algorithms. The project is also a good learning experience in mechanical design, integration of electronics and embedded programming.

The paper presents the development and design of an affordable quadruped robot constructed using easily accessible components, such as servo motors, an Arduino Nano microcontroller, and 3D-printed mechanical parts. The main goal of this work is to develop a lightweight robotic platform capable of stable walking using basic gait algorithms. By relying on widely available electronic and mechanical components, the robot becomes simpler to assemble, maintain, and modify, making it suitable for educational and experimental purposes. This project also serves as a valuable learning platform for understanding important aspects of robotics, including mechanical structure design, electronic system integration, and embedded system programming. Through the process of building and programming the robot, students gain hands-on experience in robotic system development, such as constructing mechanical assemblies, writing microcontroller code, and evaluating locomotion performance. This practical approach helps connect theoretical concepts with real-world engineering practice and promotes creativity, problem-solving skills, and further experimentation in robotics.

METHODOLOGY

Components

The quadruped robot is composed of several mechanical and electrical parts which are interconnected to provide locomotion. Servo motors function as actuators of the movement of the joints of the robot legs. They receive pulse-width modulated (PWM) signals from the controller and rotate to desired angles to generate the needed leg motion [4].

The central control of the robot is performed by the Arduino Nano microcontroller. It receives input command and produces control signal to the servo motors. An Arduino nano expansion board is employed to make it easy to connect a variety of servos and electronic components.

A buck converter is employed to control the voltage fed by the battery to make the Arduino and servo motors run smoothly. The system has also got an HC-05 Bluetooth module that enables wireless communication between the robot and a smartphone or a computer [5].

Figure 1 illustrates the mechanical design of the robot where 3D-printed parts are used to construct the robot. Each leg has the major components of coxa (hip joint), the femur (thigh), and the tibia (lower leg). These sections are 3D printed with PLA material and made with screws to construct a lightweight and strong construction. The power supply to the entire system is given by a lithium-ion battery [6–7].

Flow Diagram

The quadruped robot works by being started by the user passing on the commands via a smartphone application using Bluetooth. These commands are sent to the Bluetooth module which sends them to the Arduino Nano microcontroller via serial communication.

Using the commands received by the microcontroller, it calculates the necessary movement pattern. Depending on a set of predetermined gait algorithms, the controller produces PWM signals, which drive the servo motors attached to every joint of the legs [8].

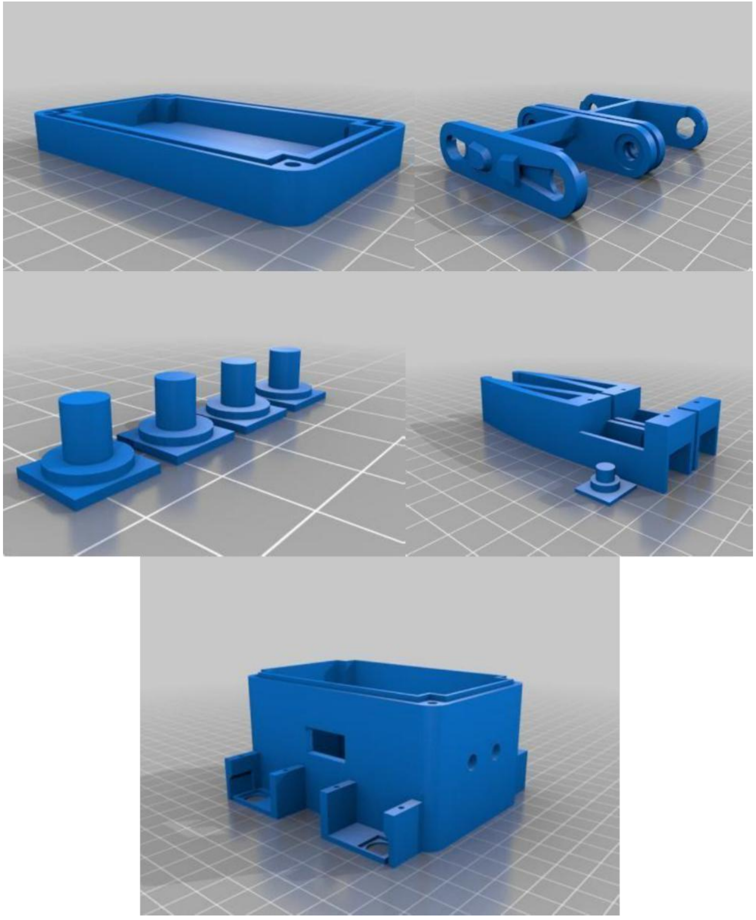

Figure 1. 3D printed parts.

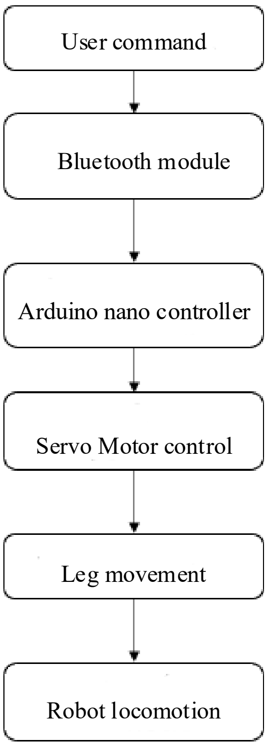

Figure 2. Flow diagram.

These servo motors are rotated to certain angles, which create and generate synchronized movements of legs that help the robot to walk, turn, or stop. The general process of work may be described in a sample form as presented in Figure 2:

Software–Hardware Integration

The quadruped robot is a combination of both hardware and software to attain stable locomotion. The program is written in Arduino Integrated Development Environment (IDE). The generation of PWM signals to turn the servo motors is carried out with the help of the Servo library.

The robot has two servo motors in each leg to move the knee and hip as well as giving the robot several degrees of freedom. Through the angular position of these servos, a coordinated movement of the legs is attained [9].

The Bluetooth interface will be connected to the Arduino via a serial connection and thus the robot will be able to receive wireless commands sent by an external gadget like a smartphone. These commands are decoded by the microcontroller which processes a pre-programmed series of movements like forward walk or turning. Figure 3 demonstrates circuit diagram.

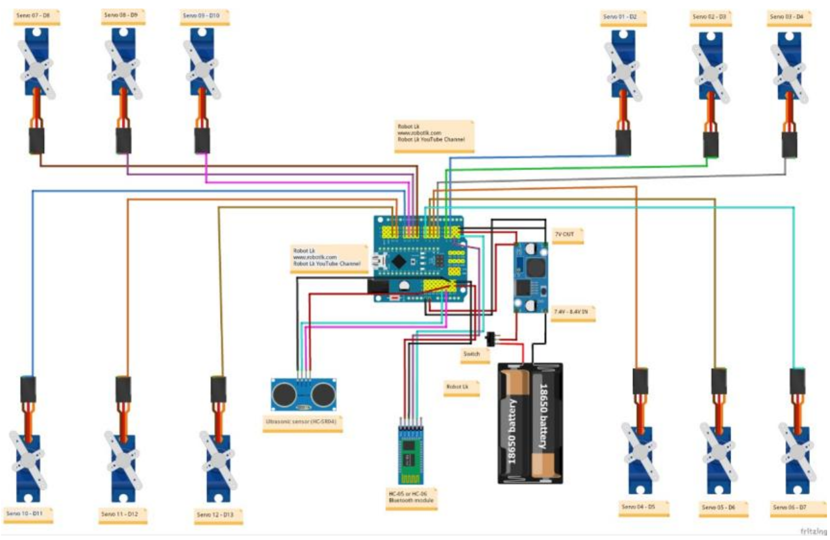

Figure 3. Circuit diagram.

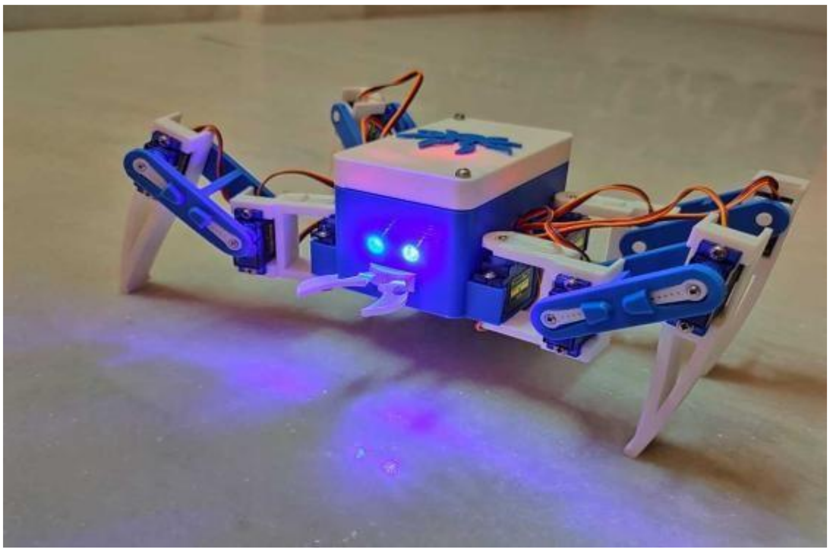

Figure 4. Working quadruped robot.

Testing

The robot was put through a test on a flat area after finishing installation of the mechanical and electronic parts. The calibration of servo motors was done so that the movement was symmetrical and the legs were aligned.

Various motion commands like walking forward, left, right, and stop were put into test using Bluetooth control. The robot was tested in terms of stability during movement and the servo angles were slightly tweaked to enhance the stability of the robot [10].

The power supply system was also checked to be able to keep the buck converter supplying the microcontroller and the servo motors with constant voltage to work. Figure 4 is a working quadruped robot.

RESULTS AND DISCUSSION

The constructed quadruped robot was able to perform the crawl gait pattern of locomotion. In this gait, the leg takes a step one after the other and the other three legs all on the ground. This guarantees the stability of the robot in a very still position, with the center of gravity contained in the support or polygon of the supporting legs.

The 3D-printed components enabled the robot to have a lightweight design and accommodate the required electronic components. It was also easy to test using the modular design which helped in assembling and modifying the robot.

The Arduino Nano microcontroller was functional in the control of the servo motors as well as running the gait patterns that were programmed. The HC-05 Bluetooth module was used in wireless control to enable the robot to accept a command via a smartphone and make the required movement.

In the course of the testing, the robot managed to walk forward and turn on even surfaces. There were however certain limitations favored. Small servo motors limit the number of payloads that the robot can carry and continuous use may result in additional consumption of power and heating of the motors.

In Despite these constraints, the findings indicate that a working quadruped robot can be constructed with low-cost parts and, nevertheless, it is able to provide the robot with stable locomotion. The project offers the solid base to the future improvement and experimentation of legged robotics.

Future Improvements

Although the current quadruped robot prototype successfully demonstrates basic walking motion and provides a valuable educational platform, there are several areas where the system can be improved in the future. Enhancing the robot's mechanical structure, control algorithms, sensing capabilities, and communication features would significantly increase its performance and expand its use in educational robotics research. The following subsections describe potential improvements that could be implemented in future versions of the robot.

Sensor Integration and Environmental Awareness

One important improvement involves the addition of sensors that allow the robot to better understand and interact with its surroundings. At present, the robot primarily performs predefined movements based on programmed instructions. By integrating sensors, such as ultrasonic sensors, infrared sensors, or an inertial measurement unit (IMU), the robot could detect obstacles, measure distance, and monitor its orientation. These sensors would enable the robot to respond to environmental changes and adjust its movements accordingly. For example, obstacle detection would allow the robot to avoid collisions, while orientation sensing could help maintain balance when moving on uneven terrain. Incorporating these sensing systems would make the robot more autonomous and suitable for experiments related to navigation and environmental interaction.

Improvement of Gait and Control Algorithms

Another key area for future work is the development of more advanced locomotion algorithms. The current robot relies on simple gait patterns that allow it to walk steadily but may limit its speed and adaptability. In future designs, different gait patterns, such as trot, pace, or bound could be implemented to improve locomotion efficiency. These gaits are commonly observed in animals and can help distribute weight more effectively across the robot's legs during movement. In addition, optimization techniques can be applied to refine joint motion and timing so that the robot moves more smoothly. Advanced control strategies, including adaptive control or basic machine learning methods, could also be explored. These approaches may allow the robot to adjust its movements based on feedback from sensors and environmental conditions.

Mechanical Design Optimization

The mechanical design of the robot can also be further refined to enhance its durability and performance. Although the current structure uses lightweight materials and 3D-printed components, improvements in design could increase strength while reducing unnecessary weight. Future models may include reinforced joints, improved leg mechanisms, and more efficient link arrangements. Such modifications would provide better stability and a wider range of motion for each leg. Additionally, optimizing the placement of motors and structural components could improve the robot's balance and reduce mechanical stress during operation. These design enhancements would allow the robot to perform more complex movements, including climbing small obstacles or walking on sloped surfaces.

Wireless Communication and User Interaction

Adding wireless communication capabilities is another promising direction for improvement. By integrating Bluetooth or Wi-Fi modules, the robot could be controlled remotely using a smartphone, tablet, or computer. This would make the system more interactive and convenient for demonstrations in classrooms or laboratories. A graphical user interface or mobile application could also be developed to allow users to adjust gait parameters, monitor system status, and send movement commands in real time. Such features would greatly enhance the educational value of the robot, enabling students to experiment with different control strategies and observe the results immediately.

Power Efficiency and Energy Management

Power management is another aspect that could benefit from future development. The robot currently operates using standard power supplies that may limit its operating time. Using high-capacity rechargeable lithium batteries or implementing more efficient power regulation circuits could extend the robot's runtime. Additionally, improving the efficiency of motor control and reducing unnecessary energy consumption would make the system more reliable during longer experiments or demonstrations.

Expansion For Advanced Educational Applications

Finally, the quadruped robot platform could be expanded to support additional learning modules in robotics and artificial intelligence. For example, future versions may incorporate camera systems for basic computer vision tasks, path-planning algorithms for autonomous navigation, or decision-making algorithms for intelligent behavior. These additions would transform the robot from a simple walking machine into a more comprehensive educational tool. By supporting experiments in sensing, control, and artificial intelligence, the platform could help students gain deeper practical knowledge of modern robotics technologies.

CONCLUSION

The paper gave a design and construction of a low-cost quadruped robot with servo motors, Arduino Nano microcontroller, and 3D-printed mechanical designs. Embedded programming, mechanical design and wireless communication allowed the robot to carry out the simplest locomotion activities which included walking and turning.

The execution of a developed robot indicates that one can attain successful quadruped locomotion with minimal hardware and control software. The platform is a great instructional aid to students of robotics, mechatronics, and embedded systems.

Further development can involve the addition of more sensors under the category of inertial measurement unit (IMU), sensors that detect obstacles, and better gait algorithms to achieve greater stability and capability to adapt to different terrains. The performance of the quadruped robot could be enhanced in other ways through autonomous navigation and advanced control strategies.

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