



Humanoid Robot: A Step Towards Intelligent Robotics

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Abstract: Humanoid robots play an important role in modern education by providing an interactive and practical learning platform for students. Unlike conventional educational robots, humanoid robots are capable of mimicking human movements, which enhances student engagement and understanding of robotics concepts. This paper presents the design and control of a humanoid robot developed using the Arduino Mega 2560 Pro Mini for educational applications. The proposed humanoid robot consists of multiple servo motors to achieve articulated movement in the head, arms, and legs. The mechanical structure of the robot is designed using Fusion 360, allowing modular construction and easy modification. The Arduino Mega is selected as the main controller due to its ability to handle multiple servo motors simultaneously. The robot demonstrates stable motion control and synchronized joint movement, making it suitable for laboratory demonstrations and robotics education [1].

Keywords: Humanoid Robot, Arduino Mega, Educational Robotics, 19-DoF Kinematics, STEM Education

I. INTRODUCTION

Robotics is now a cornerstone of STEM education, yet institutions face a stark dilemma when selecting hardware: they must choose between high-fidelity research platforms like the SoftBank NAO, which cost upwards of \$10,000, or inexpensive hobbyist kits that lack mechanical complexity. While accessible, standard 6-to-8 Degree of Freedom (DoF) kits are mechanically restricted to simple shuffling motions, making them unsuitable for teaching critical concepts like Zero Moment Point (ZMP) stability and lateral balance.

This forces many students to learn on simulation software, missing the crucial experience of managing real-world physical constraints. To bridge this gap, we present **QUBO-Mega**, a low-cost, 19-DoF humanoid platform powered by the Arduino Mega 2560. Unlike entry-level kits, this robot features a 19-servo configuration that includes critical **hip yaw and roll joints**, enabling it to shift its center of mass laterally for true bipedal walking and autonomous fall recovery. By leveraging the Arduino Mega's high I/O count for direct actuator control and a modular 3D-printed chassis, the proposed system offers a sophisticated yet affordable testbed for students to experiment with advanced kinematics and embedded control theory.

II. LITERATURE REVIEW

Humanoid robots have become an important tool in STEM education due to their ability to mimic human motion and provide interactive learning experiences. Unlike simulation-based learning, physical humanoid platforms allow students to understand real-world challenges such as balance, actuator limitations, and weight distribution. These robots enhance engagement and help learners grasp complex concepts such as kinematics and human-robot interaction more effectively. Educational studies emphasize that humanoid robots improve practical understanding and problem-solving skills among students [4].

Commercial humanoid robots such as **SoftBank NAO** provide advanced capabilities including vision processing, speech recognition, and autonomous navigation. However, their high cost limits accessibility for many educational institutions, particularly in developing regions. As a result, researchers have focused on developing low-cost humanoid platforms that retain essential functionalities while remaining affordable and easy to maintain [5].

Microcontroller-based humanoid robots have emerged as a cost-effective alternative for educational use. The **Arduino Mega 2560** is widely adopted due to its large number of digital I/O pins, ease of programming, and ability to control multiple servo motors directly using PWM signals. This eliminates the need for additional servo driver boards, reducing system complexity and cost while maintaining reliable performance for embedded control applications [9].



The number of Degrees of Freedom (DoF) in a humanoid robot significantly influences its movement capabilities and educational value. Low-DoF robots are limited to basic motions, whereas multi-DoF robots enable realistic human-like movement, lateral balance, and gait experimentation. Research highlights that higher DoF systems allow students to explore advanced robotics concepts such as forward and inverse kinematics, center of mass control, and stability mechanisms, which are essential for understanding humanoid locomotion [7].

Servo motors are commonly used in humanoid robots due to their precision and ease of control. Studies on motion control emphasize the importance of synchronized servo movements and incremental angle transitions to achieve smooth motion and prevent mechanical stress. Open-loop control strategies are often used in educational robots for simplicity, while advanced systems incorporate sensor feedback for closed-loop stability and adaptive walking on uneven terrain [8].

The use of CAD tools and additive manufacturing has significantly improved the development of low-cost humanoid robots. Software such as **Fusion 360** enables precise mechanical design, rapid prototyping, and modular construction. 3D printing allows customization and easy replacement of parts, making humanoid robots more accessible and adaptable for educational and research purposes [9].

Despite these advancements, a gap remains between expensive research-grade humanoids and low-cost educational kits. Many affordable robots lack sufficient degrees of freedom to demonstrate realistic balance and motion control. This gap highlights the need for a low-cost, modular, multi-DoF humanoid platform that supports both fundamental learning and advanced experimentation in robotics education [4][7].

III. METHODOLOGY

The development of the humanoid robot followed a structured methodology involving design, fabrication, hardware integration, programming, and testing. Initially, the mechanical structure was designed using **Fusion 360** to create a modular, lightweight, and stable humanoid body capable of supporting 19 Degrees of Freedom (DoF). The design included separate components for the head, torso, arms, and legs, ensuring proper weight distribution and ease of assembly. These components were fabricated using 3D printing and assembled using screws and brackets to achieve structural rigidity. For hardware implementation, the **Arduino Mega 2560 Pro Mini** was selected as the main controller due to its high number of digital I/O pins and ability to control multiple servo motors directly using PWM signals.

A total of 19 servo motors were installed at critical joints, including the neck, shoulders, elbows, hips, knees, and ankles, enabling human-like articulation and improved balance through lateral weight shifting. An external battery pack was used to supply sufficient current to the servos, while a common ground configuration ensured stable and noise-free operation. The software was developed using **Arduino IDE**, where each servo was assigned to specific pins and initialized to default positions for a stable startup posture. Motion control was achieved through predefined movement sequences such as standing, arm gestures, head rotation, and leg articulation.

Smooth and synchronized motion was ensured by implementing incremental angle transitions and controlled delays, reducing jerks and improving stability. Finally, the system underwent testing and calibration, including individual servo testing, joint range adjustments, and stability evaluation through center-of-mass shifting. The fully assembled humanoid robot demonstrated coordinated multi-joint movements and stable posture, making it an effective and low-cost platform for robotics education, kinematics experimentation, and embedded systems learning [2].

1. SYSTEM DESIGN AND ARCHITECTURE

The humanoid robot system is designed to perform coordinated movements using multiple servo motors (19 Servo Motors) controlled by a single microcontroller.

A. Overall Architecture

The system consists of:

- [1] Arduino Mega 2560 Pro Mini as the main controller
- [2] Multiple servo motors for limbs and head movement
- [3] External battery supply for servo operation
- [4] Mechanical frame



2. Hardware Design

A. Arduino Mega 2560 Pro Mini

We chose the Arduino Mega 2560 Pro Mini as the central controller for a specific practical reason: its I/O capacity. Most beginner boards like the Uno do not have enough pins, and computers like the Raspberry Pi require complex OS management for real-time motor control. The Mega provides 54 digital pins, which allows us to control all 19 servos directly

B. Servo Motors

Servo motors are used to provide precise angular movement for each joint. The humanoid robot uses servos for:

- A. Right and left legs
- B. Right and left arms
- C. Head movement

Each servo is controlled using PWM signals from the Arduino Mega.

C. Significance of 19 Degrees of Freedom

The use of 19 Degrees of Freedom provides several advantages over low-DoF educational robots:

1. Realistic Human-Like Movement

A higher number of DoF allows the humanoid robot to perform complex and natural movements, improving realism and interaction.

2. Enhanced Learning of Kinematics

Students can study joint rotation, link movement, and forward and inverse kinematics more effectively using a multi-DoF system.

3. Independent Joint Control

Each servo motor can be controlled individually, enabling precise motion planning and experimentation with different gait and posture algorithms.

4. Improved Balance and Stability

Multi-DoF legs help distribute movement across joints, reducing sudden load on a single joint and improving overall stability. The main advantage of this robot over standard educational kits is its 19 Degrees of Freedom (DoF). Most low-cost robots use only 6 to 8 motors, which limits them to a shuffling motion because they cannot lift their legs sideways. Our design includes **Hip Yaw and Roll joints**, which are critical for "Lateral Stability."

This allows the robot to shift its Center of Mass (CoM) sideways over one foot to balance, just like a human does when walking.

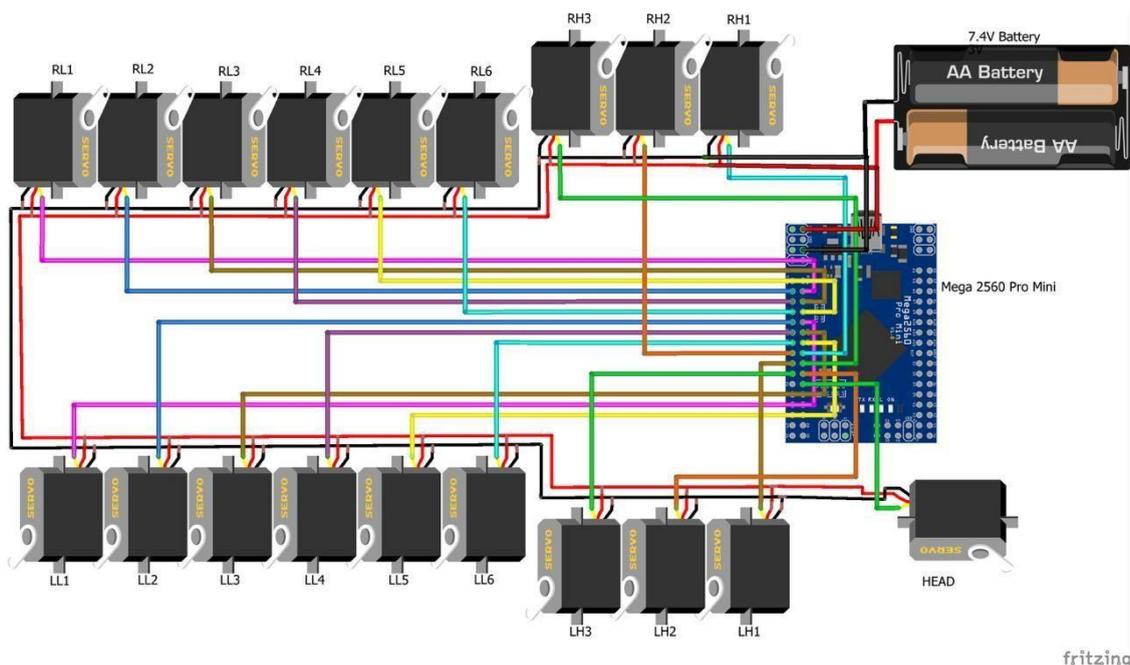


Fig 3.1 Overall Circuit Diagram of Humanoid

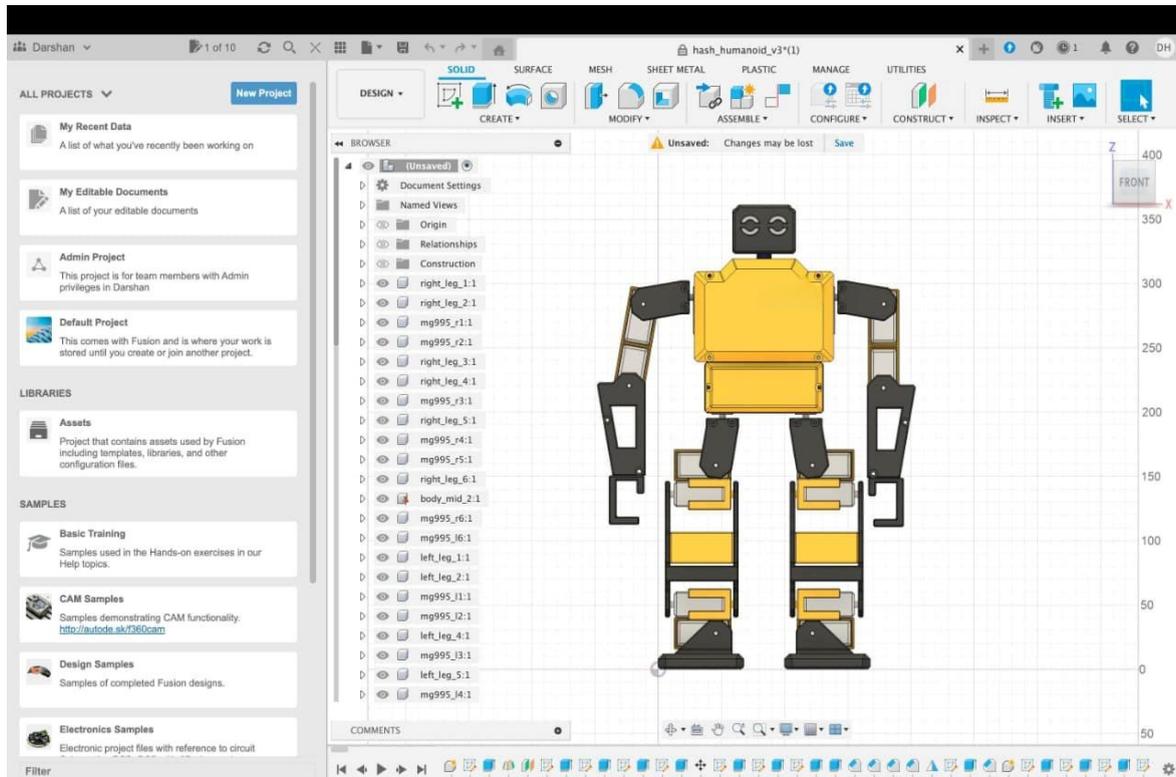


Fig 3.2 19 DoF Humanoid Design in Fusion 360

IV. RESULT AND DISCUSSION

The developed 19-DoF humanoid robot was successfully designed, assembled, and tested as a low-cost educational platform. The system demonstrated stable operation with coordinated control of all servo motors using the Arduino Mega 2560 Pro Mini, confirming its capability to handle multiple actuators simultaneously without the need for external servo drivers. The modular structure designed in Fusion 360 provided adequate strength while maintaining a lightweight form, enabling smooth joint articulation and ease of maintenance.

During testing, the robot achieved synchronized movements including arm lifting, head rotation, leg bending, and stable standing posture. The implementation of incremental angle transitions and motion synchronization in the Arduino IDE program reduced jerky movements and improved overall stability. The inclusion of hip yaw and roll joints allowed lateral shifting of the center of mass, enhancing balance and demonstrating principles of humanoid stability.

From an educational perspective, the robot proved highly effective as a hands-on learning tool. It enables students to understand servo control, embedded programming, kinematics, and real-world mechanical constraints. Compared to low-DoF educational kits, the 19-DoF configuration provides more realistic human-like motion and supports advanced experimentation such as gait planning and balance control.

However, some limitations were observed. The robot currently operates using open-loop control without sensor feedback, which restricts autonomous balance and adaptive walking on uneven surfaces. Power consumption is also significant due to multiple servos operating simultaneously. Future improvements may include integrating IMU sensors for closed-loop balance control, implementing computer vision for interaction, and optimizing power management.

Overall, the results demonstrate that the proposed humanoid robot successfully bridges the gap between affordability and functionality, making it a practical platform for STEM education, robotics research, and skill development.



Fig 4.1 Final output

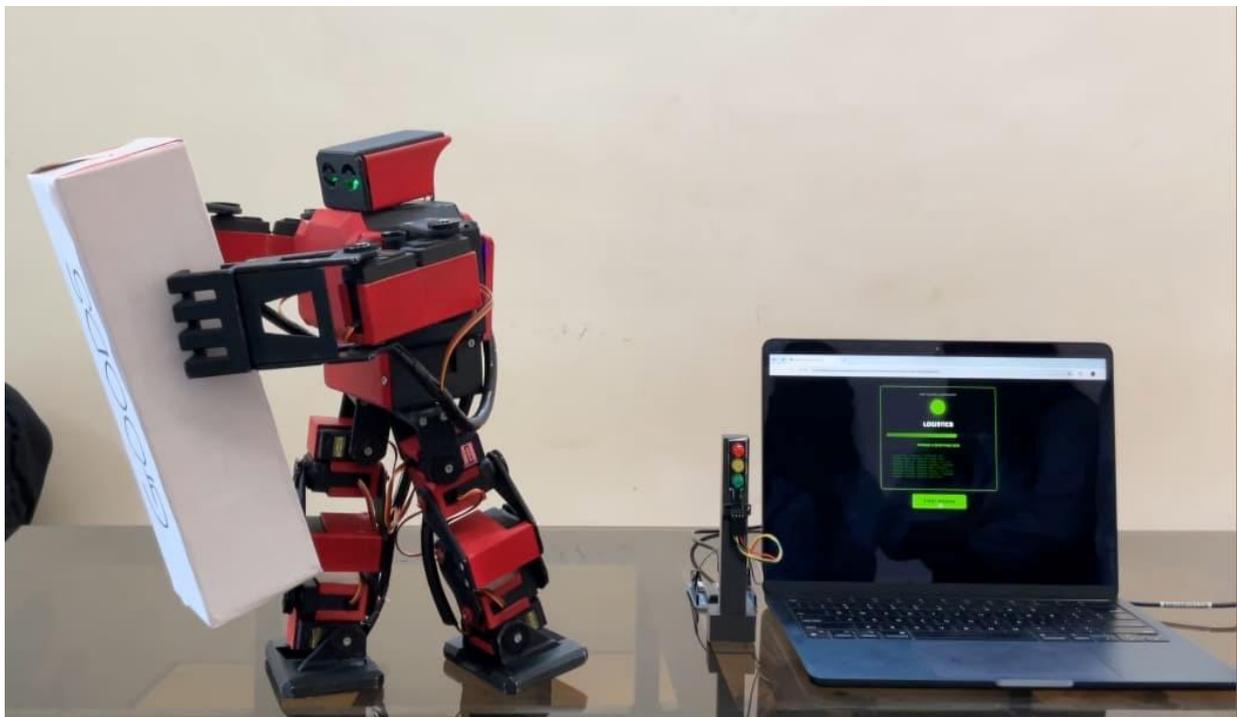


Fig 4.2 Working of Humanoid Robot

V. APPLICATIONS

1. **STEM Education:** Used as a hands-on tool to teach robotics, kinematics, and embedded systems concepts.
2. **Locomotion Research:** Enables experimentation with balance, gait planning, and center-of-mass control.
3. **Human-Robot Interaction:** Helps study gesture-based communication and user engagement with robots.
4. **Exhibitions & Competitions:** Demonstrates human-like movements to explain robotics in an engaging way.



5. **Embedded & IoT Training:** Serves as a platform for integrating sensors, wireless modules, and real-time control.
6. **Service Robot Prototype:** Can be adapted as a reception, guide, or smart classroom assistant.
7. **Hazardous Environment Use:** Can be upgraded for inspection tasks in environments unsafe for humans.
8. **Skill Development:** Encourages innovation and practical learning in robotics and automation.

VI. CONCLUSION

This paper presented the design, development, and control of a humanoid robot built using the Arduino Mega 2560 Pro Mini for educational applications. The proposed system demonstrates how a low-cost and modular humanoid platform can be developed to bridge the gap between theoretical learning and practical implementation in robotics education. By incorporating 19 Degrees of Freedom (DoF) through multiple servo motors, the humanoid robot achieves human-like articulation, enabling students to observe and experiment with real-world motion dynamics, joint coordination, and balance control.

The mechanical structure, designed using Fusion 360, ensures a lightweight yet robust framework that supports modular assembly and easy maintenance. This modularity allows educators and students to modify or upgrade individual components without redesigning the entire system, thereby extending the robot's usability for various experiments and research activities. The use of direct PWM-based servo control eliminates the need for costly external drivers, significantly reducing overall system cost while maintaining reliable performance.

From a software perspective, programming through the Arduino IDE enabled precise control of individual joints and synchronized motion sequences. The implementation of smooth motion control techniques improved stability and reduced mechanical stress, demonstrating practical aspects of embedded control systems and motion planning. As a result, the humanoid robot serves as an effective platform for teaching key concepts such as kinematics, embedded systems, control logic, and system integration.

The developed platform is scalable and adaptable, making it suitable for a wide range of educational levels, from basic robotics training to advanced research in humanoid locomotion and human-robot interaction. By providing an affordable alternative to expensive commercial humanoids, the proposed system democratizes access to high-fidelity robotics education and encourages innovation among students and researchers.

In conclusion, the humanoid robot not only enhances practical understanding of robotics concepts but also fosters creativity, problem-solving skills, and hands-on learning. Its low-cost, modular, and extensible design makes it a valuable contribution to the field of educational robotics and a strong foundation for future advancements such as sensor-based feedback control, autonomous navigation, and intelligent human-robot interaction [3].

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