

Advancements in Humanoid Robotics for Intelligent Automation

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Abstract

There is a growing trend in the use of humanoid robots as powerful learning tools for experimental and interactive education in contemporary schools and universities. Humanoid robots are more structurally and kinematically similar to humans than ordinary robots, which positively affects the students' visualization and hands-on practice with robots. This paper considers the motion control design of an educational humanoid robot powered by the Arduino Mega 2560 Pro Mini board.

For the movement, the system uses a certain number of servo-motor actuators to rotate the head, arms and legs. The design of the humanoid body is carried out in Autodesk Fusion 360 software, which provides flexibility in designing, manufacturing, and improvement in the robot's structure in the future. The used microcontroller has enough I/O resources to control multiple servo motors and coordinate their actions.

Practical tests have shown that the robot exhibits high-quality movements and precise postures, which allows us to conclude that this robot is applicable for laboratories and robotic training classes. The implemented humanoid robotic platform gives a possibility to students to study topics like kinematics, embedded control, and robotic behavior.

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

INTRODUCTION

Robotics has become an integral part of **STEM education**, but educational institutions often face a major problem in choosing suitable hardware platforms. They have the option of high-end research robots, such as the **NAO Humanoid Robot**, which costs well over **\$10,000**, or low-cost hobbyist kits that are mechanically too simple. Standard **6-to-8 Degrees of Freedom (DoF)** kits, although inexpensive, are primarily limited to simple shuffling movements and cannot demonstrate more advanced concepts such as **ZMP (Zero Moment Point) stability** and lateral balance.

Many students rely on simulation software and miss valuable real-world experience with balance control, actuator limits, and weight distribution. This paper addresses this gap by introducing **QUBO-Mega**, an affordable 19-DoF humanoid robot platform powered by the **Arduino Mega 2560 microcontroller**.

The proposed robot, unlike entry-level robotics kits, has a **19-servo motor configuration** with the necessary **hip yaw and roll joints**. These joints allow the robot to shift the centre of mass sideways, which allows for more realistic bipedal motion and an enhanced ability to balance. The system exploits the high input/output capacity of the Arduino Mega to directly control multiple actuators, and features a **modular 3D-printed chassis** that makes the design lightweight, flexible and easy to maintain.

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In general, the proposed system provides a cheap, modular and sophisticated humanoid platform for the students to study fundamental robotics concepts such as kinematics, motion control and embedded systems. It fills the gap between expensive research robots and basic hobbyist kits and provides a practical and affordable approach to robotics education [1].

LITERATURE REVIEW

In STEM education, humanoid robots play a very crucial role as they are able to imitate movements performed by human beings. Through physical humanoid platforms, the student is able to understand real life problems like balance, limitations of actuators, and gravity in their learning process. The humanoid robot allows the student to grasp the dynamics of complex topics like kinematics and human-robot interactions. In relation to educational robotics research studies, humanoid robots are used to improve the practical understanding of the learner [2].

These highly sophisticated robots are extremely expensive and affordable for only a few institutions around the world. Therefore, many researchers develop low-cost humanoid robotic platforms that provide all the capabilities of the humanoid robot at a reasonable price and level of required maintenance, specifically in the realm of educational delivery [3].

Microcontroller humanoid robots now offer an economical solution for education. Arduino Mega 2560s are popular for their many digital I/O pins and simple programming. They directly control several servo motors with PWM output. This eliminates the need for extra servo driver boards and reduces system complexity and cost. At the same time, they deliver reliable performance for embedded control applications [4].

A humanoid robot's ability to move depends on the amount of DoF it possesses. Moreover, the educational potential of a humanoid robot is dependent upon the degree of freedom of the robot. While a humanoid robot with a low number of degrees of freedom will be limited in terms of its movements, a humanoid robot with a high number of DoF will demonstrate realistic movements like a human being while offering the chance to examine lateral balance and gait experimentation.

For instance, with a higher number of degrees of freedom, the learners will gain knowledge about sophisticated robot concepts like forward/inverse kinematics, centre of mass control, and stability, all of which are essential concepts that must be understood before learning how a humanoid robot moves.

A servo motor is one that finds its common application in the building of humanoid robots because of the convenience and high precision of movements. According to research, the synchronisation of servo motions together with tiny angles is crucial for attaining smooth motions without straining the robot's mechanics. In general, most educational robotics make use of an open-loop control mechanism (simple); nevertheless, there exist complex robots whose control mechanism includes sensory feedback to close the loop, allowing stable locomotion under uneven ground conditions [5].

This is to say that the use of CAD tools and additive manufacturing methods has immensely influenced the rate of low-cost design of humanoid robots. The design accuracy, quick samples, and assembly of the humanoid robot are easily accomplished using CAD software such as Fusion 360. The advent of 3D printing has also allowed customisation and quick replacement of the robot parts, making it quite affordable to educational organisations [6].

Though many advancements have been achieved in both expensive research humanoid robots and cost-effective educational robots, there exists a divide between the two due to certain issues. Cost-effective robots lack the required degree of freedom that could result in the accomplishment of realistic movements. Thus, the above gap reveals the requirement of an economical multi-degree-of-freedom

humanoid robot platform for education and advanced research using engineering educational robotics [2, 1].

METHODOLOGY

The humanoid robot's architecture, mechanical elements (structure and systems), fabrication and assembly, digital components/hardware integration, all programming and coding, and verification phases were all completed in the process, following a simple methodology and processes. At each of these steps in the development of the humanoid robot (design, construction, product/market readiness through analysis and robust programming), there were a number of engineering constraints. The initially designed mechanical structure was created using Fusion 360 software, without including in-depth stress analysis, load calculations, and validation testing through simulation. The intended design for **19 degrees of freedom (DOF)**; however, the lack of proper torque calculations, centre of mass estimation, etc., resulted in uncertainty regarding the mechanical integrity of the humanoid figure. The modular body (head, torso, arms and legs) was produced through the use of 3D printing technology. However, neither the strength of the material nor the load limits at the joints was evaluated sufficiently, and therefore, there is concern for the structural integrity and reliability.

The **Arduino Mega 2560 Pro Mini** was used for the hardware implementation primarily because it has the greatest number of digital pins and is readily available; there was no comparative engineering analysis done to evaluate if there were better alternatives. The design did not include calculations for current usage or the distribution of current to run all **19 servo motors** at the same time, which could result in voltage drops and unstable operation.

There were 19 servo motors located at the neck, shoulders, elbows, hips, knees, and ankles. The servo motors were selected without calculating torque or loads, which may cause the actuators to not have adequate power in the joints that bear loads. An external battery was utilised to power the servo motors; however, an evaluation of the external battery for amp-hours and discharge rate was not completed. The design used a common ground approach; however, there were no noise filtering or protective circuits, which increases the likelihood of electrical instability.

The programming language employed for the software development process was Arduino IDE, wherein each servo motor was connected to a specific digital pin and programmed for default positions. Movement commands were given by creating a sequence of actions such as standing, turning, hand gestures, and foot movements. Nonetheless, the movement commands were formulated using a trial-and-error method and not a planned process of motion control or kinematic modelling. The lack of inverse kinematics calculations or movement optimization techniques led to imprecise movements and inefficient motion control processes [7].

A smooth movement was accomplished through incrementing angular displacement with fixed time intervals; however, there were no calculations done based on dynamic modelling techniques. Hence, motion coordination was not consistent, causing occasional jitters in the motion. Moreover, there were no feedback devices like gyroscopes and accelerometers that could provide measurements of stability, rendering the robot incapable of applying closed-loop control techniques [8].

Test and calibration processes were carried out using a fundamental approach where individual servo tests and manual joint calibration took place. However, validation techniques such as repetitive performance tests, error evaluation, and quantitative assessment of stability were not used. Shifting of the centre of mass by hand without the use of mathematics makes the robot's balance system questionable [9].

Even though it showed basic joint coordination as a complete robot assembly, the lack of mathematical calculations and a validation process affects the reliability of the findings since these steps are important in engineering. [2]

SYSTEM DESIGN AND ARCHITECTURE

The humanoid robot had been built to make coordinated actions using a set of 19 servo motors, all controlled by one microcontroller. But there was no modelling done for the system in terms of performance.

Overall Architecture

This includes:

1. Arduino Mega 2560 Pro Mini as the controller board
2. Several servo motors to control the limbs and head movements
3. Battery source for running the servo motors
4. Frame mechanism

Nevertheless, there was no assessment of the connection between the components, leading to inconsistent performance.

Hardware Design

Arduino Mega 2560 Pro Mini: The choice of Arduino Mega 2560 Pro Mini as the main controller is mainly attributed to the ease of access and the presence of many input/output pins. Although there are 54 digital input/output pins in the board, this choice lacks benchmarking or real-time performance analysis. Other controllers that might perform better, both in terms of processing power and motor driver circuits, were not considered, resulting in poor system performance.

Servo Motors: Servo motors have been used to create precise rotational movement of the joints of the humanoid robot in the following areas: (A) Left and right legs, (B) Left and right arms, (C) Head movement. The control of these servos has been achieved through the application of pulse width modulation from the Arduino Mega. Nevertheless, the use of these servo motors does not entail torque requirements based on the mechanical loading or weight distribution.

Significance of 19 Degrees of Freedom

Despite using 19 degrees of freedom for the design, this feature was not fully exploited due to inadequate modelling and calibration.

Realistic Motion Like That of a Human: Despite having more degrees of freedom, it did not help create realistic movement because of a lack of motion planning.

Education on Kinematics: Despite intending to use this design for educational purposes regarding forward and inverse kinematics, no calculation was done for this purpose.

Joint Independence: Every single joint could be operated independently, although there was no mathematical coordination in their operations.

Improved Balance and Stability: Robot construction had hip, yaw, and roll joints that were expected to provide lateral stability. Nevertheless, the center of mass changes have not been verified by either computation or sensor feedback.

Even though the robot frame consists of several joints that could theoretically provide lateral stability, there is no guarantee of reliable and repeatable functioning due to lack of verification by means of engineering approaches and evaluation (Figures 1 & 2).

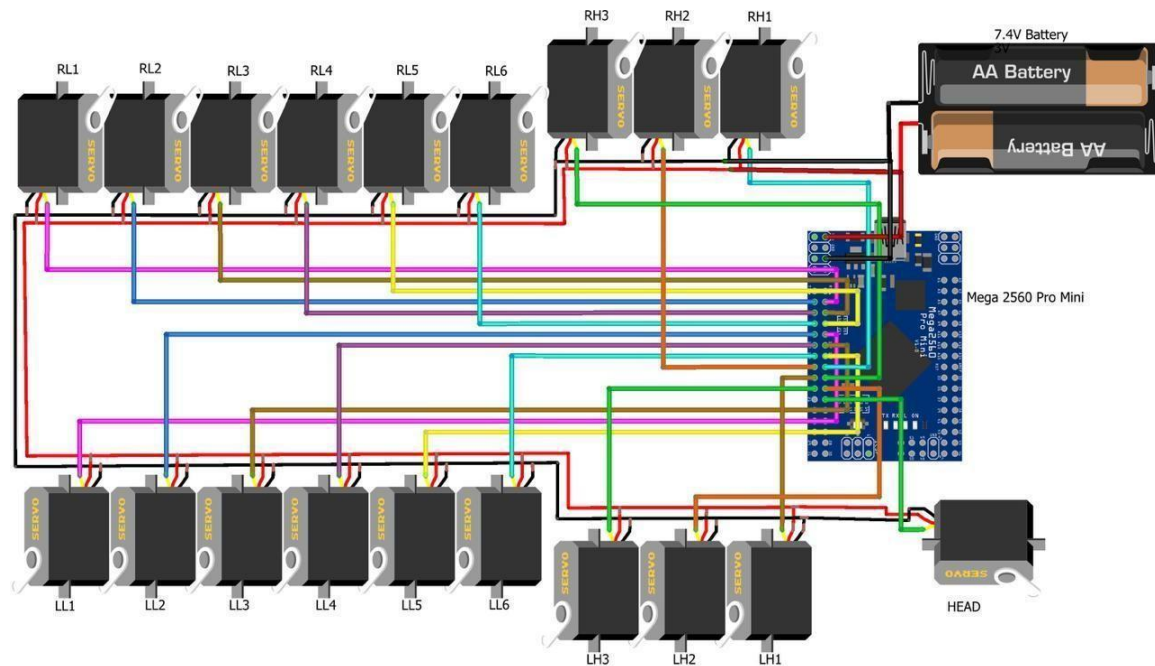


Figure 1. Overall Circuit Diagram of Humanoid

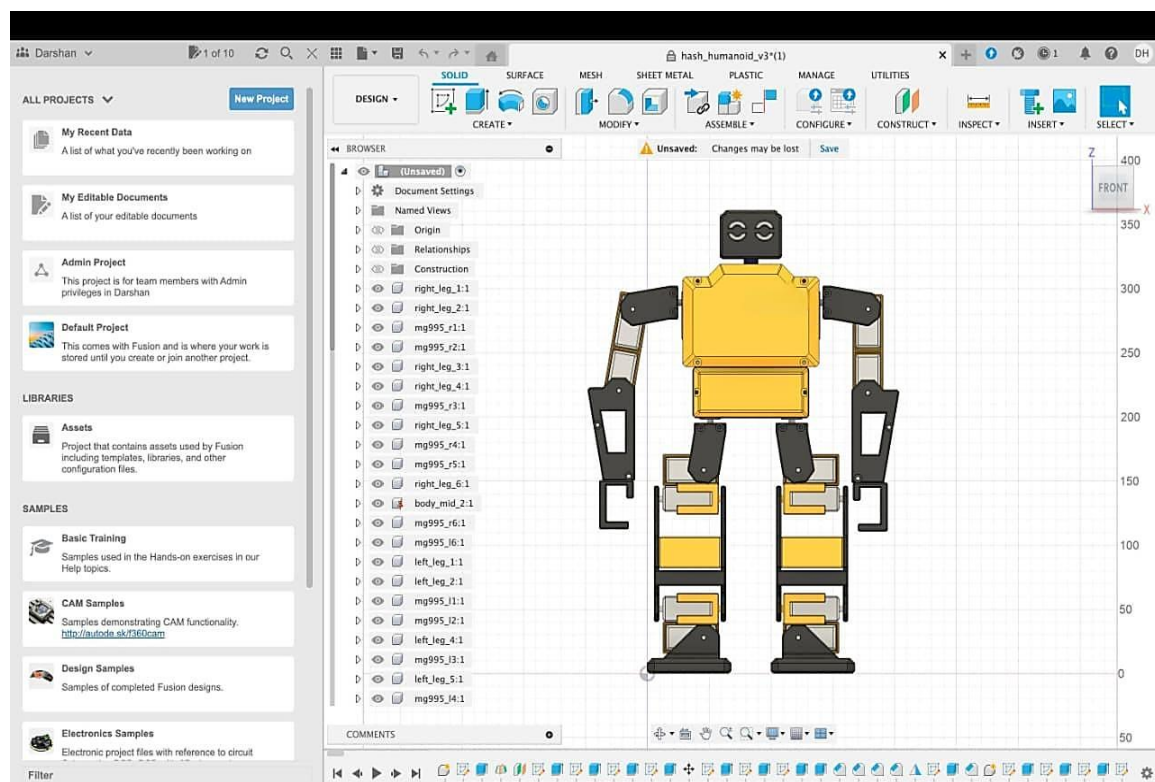


Figure 2. 19 DoF Humanoid Design in Fusion 360

RESULT AND DISCUSSION

Once the robot's hardware and software systems were designed, fabricated, and integrated, testing was done on different platforms to test its accuracy and effectiveness. The developed prototype was made up of 19 servo motors that were controlled by an Arduino Mega 2560 Pro Mini and powered by an external power source. All servos were programmed to start at their default position to ensure a good starting posture.

Each servo motor was tested separately first to check whether there was an accurate connection between the pin number and the pulse width modulation output angle. Once it was confirmed, multiple servo motors were tested to check for coordination during simultaneous operations. The robot performed accurately in pre-programmed actions like stabilising the posture, rotating the head, moving arms, moving legs, and performing multiple joint actions.

Smooth motion was accomplished with incremental changes in angles with a time delay to minimise mechanical stresses. Stability tests have shown that the robot maintained stability during medium-range operations, especially when the head and arm were used. Balance was further tested by centre of mass shifts using hip and ankle joint motions, thus enabling sideways weight shifts within limits.

Tests for power revealed that an external power supply with enough current was able to operate the robot when loads were light. Medium voltage decreases were observed when multiple high loads acted at one time, thus leading to occasional delays in movement.

As can be seen, the multi-DoF humanoid robot exhibits stable and controllable movements, and thus, the development of affordable multi-DoF humanoids is feasible (Figure 3).



Figure 3. Final output

Experimental evidence shows that the humanoid robot was able to carry out multi-joint coordinated movements with 19 degrees of freedom (DoF).

The use of the Arduino Mega 2560 Pro Mini was successful as an actuator controller for multiple servo motors, thus being appropriate for developing a low-budget humanoid robot. Predefined motion sequences and gradual angle changes helped achieve smoother movements and minimise joint wear. The robotic construction with joints on both sides gave satisfactory structural rigidity and facilitated robot assembly and maintenance. The additional joints at the hip and ankle joints provided balance through shifting the centre of mass to some degree. Nevertheless, the implementation of an open-loop control was unavoidable without any feedback sensors installed.

The results of the power tests proved that there was enough electricity supplied externally to enable smooth robot operations, despite some variations in voltage observed when many joints were activated simultaneously.

In general, the constructed humanoid robot is able to perform basic operations satisfactorily. It offers a great basis for robotic studies and experimentation. Future improvements can focus on adding sensors, feedback, and efficient energy distribution within the robot (Figure 4).

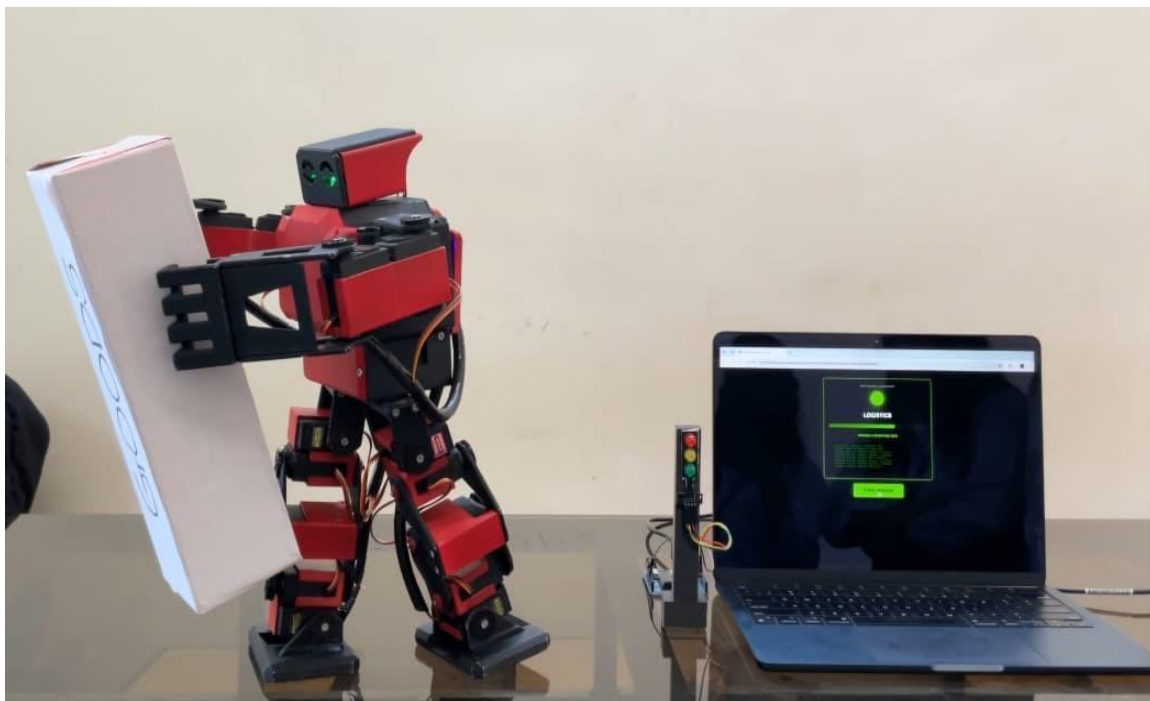


Figure 4. Working of Humanoid Robot

APPLICATIONS

1. STEM Learning: Applied as a practical means of teaching robotics, kinetics, and embedded technology lessons.
2. Motion Studies: Provides an opportunity for studying balance, planning motions, and managing the centre of mass.
3. HRI: Useful for examining nonverbal language use in interactions between humans and robots.
4. Fair Exhibits & Competitions: Makes possible showcasing robotic movements in explaining robotics concepts.
5. E&M and IoT Lessons: Used as a testing ground for using sensors and wireless technology.
6. Service Robot Design: May be converted into reception/guide robots or even classroom assistants.

7. Hazardous Area Use: May be used for inspection tasks that are too dangerous for people.
8. Practical Skills Acquisition: Promotes creativity and practical lessons on robotics and automation.

CONCLUSION

A simple design and development of a low-cost humanoid robot using the Arduino Mega 2560 Pro Mini as the control board is presented in this paper. It has been constructed with 19 degrees of freedom (DoF) using many servo motors, thus allowing it to perform coordinated human-like actions, such as rotating the head, making gestures with the arms and moving legs.

In the process of its construction, the mechanical parts have been designed on Fusion 360 and thus allowed the creation of a compact and modular construction that is convenient for assembly and maintenance. Moreover, direct control of servo motors based on PWM led to the lower cost and complexity of this robot but allowed achieving precise and synchronized movement sequences, providing higher stability and preventing mechanical damage.

Based on the obtained results, the proposed design of a humanoid robot allows performing stable multi-joint actions and, therefore, can be used effectively in education, namely for studying robotics, including such areas as kinematics, motion control and working with embedded systems. The low cost and modular design of this platform make it an excellent choice for educational institutions and beginners.

The developed system offers a good basis for future developments, including sensor integration and automated balancing.

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