DESIGN AND DEVELOPMENT OF HUMANOID ROBOT WITH AUTONOMOUS NAVIGATION

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Keywords:

Humanoid Robot, Autonomous Navigation, Robotics, Mechatronics, Artificial Intelligence.

Introduction/Background:

In recent years, robotics has emerged as a transformative technology, significantly impacting sectors like healthcare, education, and automation. Among the various branches of robotics, humanoid robots have garnered substantial attention due to their potential to replicate human actions, communicate intuitively, and adapt across dynamic environments. This project, titled *"Design and Development of Humanoid Robot with Autonomous Navigation,"* aims to create a versatile robotic platform capable of serving both educational and assistive purposes.

Drawing from previous innovations in medical robotics, the current work focuses on integrating advanced technologies such as SLAM (Simultaneous Localization and Mapping), natural language processing (NLP), and AI-driven gesture recognition. The robot is designed to operate autonomously using 3D LiDAR for navigation and interaction within its surroundings. By equipping the system with servo and stepper motor-driven limbs, a Raspberry Pi-based processing unit, and ROS for real-time control, the project seeks to enable a high level of human-robot interaction and task execution.

Objectives:

1. To serve as an educational tool for teaching students about robotics, AI, and programming.
2. To provide a research platform for faculty and students to develop and test new robotic algorithms and applications.
3. To enable continuous development, allowing future students to build on the existing design and capabilities.
4. To integrate advanced sensors and control systems that can be expanded upon by future research.
5. To integrate natural language processing capabilities for seamless verbal communication with humans.

Methodology:

The methodology followed for the development of the humanoid robot project involved a structured and iterative approach. Initially, a thorough literature review and gap analysis were conducted to understand existing technologies and identify areas for improvement. Based on this, clear research objectives were defined. The next phase involved detailed design planning and selection of appropriate technologies, including hardware components and software platforms. This was followed by the initial prototyping phase, where CAD modeling and 3D printing were used to create the robot's structure, and electronic components were integrated to form the basic arm mechanism. Data collection and testing were performed during each development stage to analyze system performance, which guided iterative refinements. The final stages involved implementation of all subsystems, extensive testing and validation, fine-tuning, and optimization to ensure stability and functionality. Finally, documentation, reporting, presentation of results, and addressing feedback concluded the process, leading to the final project handover.

Work in progress: -

Different stages of experimental work in the project served to perform essential development and testing operations on the humanoid robot. Scientists have al ready achieved considerable development of the base mobility system through construction and testing. The base assembly succeeded in its testing phase with a joystick that confirmed both the smooth operation and appropriate functioning of the system. Autonomous movement using LiDAR-based navigation will become integrated during the next phase while its obstacle detection capabilities will boost the robot's operational efficiency.

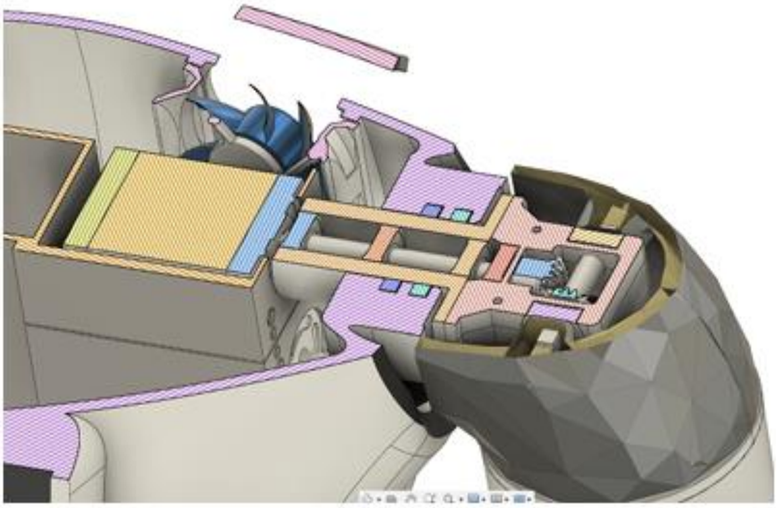

Figure 1: Open View of Shoulder

The right arm prototype development included the integration of all specially designed complex joint mechanisms which enable controlled and realistic motion functions. The shoulder, elbow, wrist and finger mechanisms underwent thorough testing to confirm their motion ability and precision of actuation. The fabrication of the left arm will start after right arm success to achieve perfect humanoid symmetry and balance.

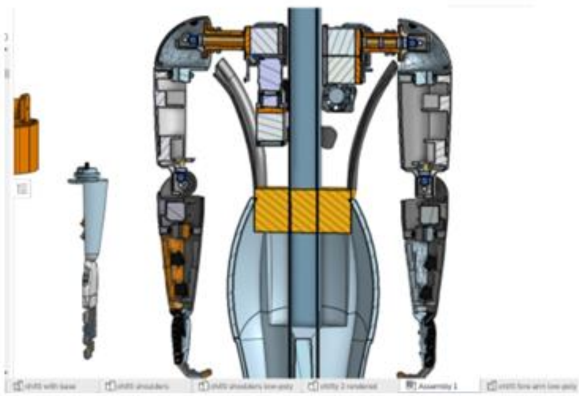

Figure 2: The Figure Illustrates the complete arms installed onto Central Humanoid Structure

The complete arms will receive final assembly stage before they are installed onto the central humanoid structure where the head assembly sits on top. The complete humanoid system will emerge when the AMR base joins with the upper body to produce a mobile and interactive platform. The project will complete by con ducting an integrated implementation of motor drivers and sensors and control interfaces to maintain complete functionality between all system elements.

Figure 3: Initial Prototype of Humanoid Robot

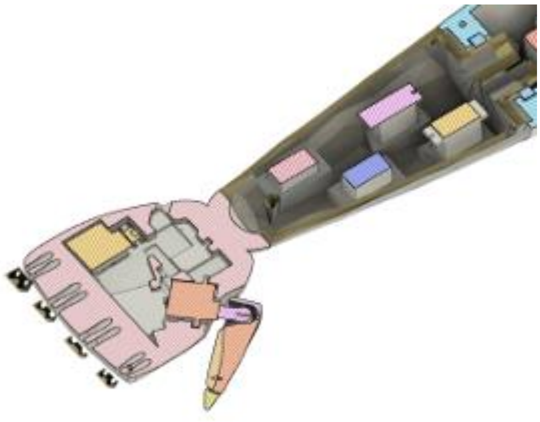

Figure 4: Open View of Wrist And Palm

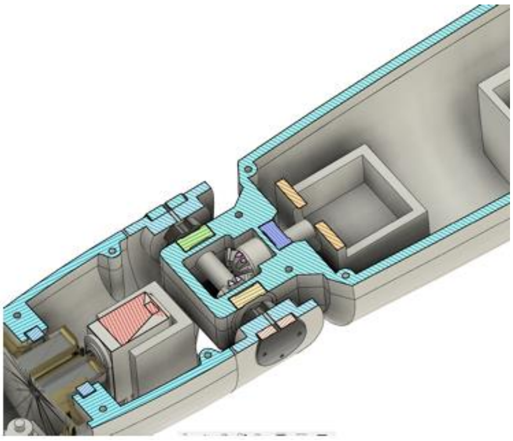

Figure 5: Open View of Wrist Joint

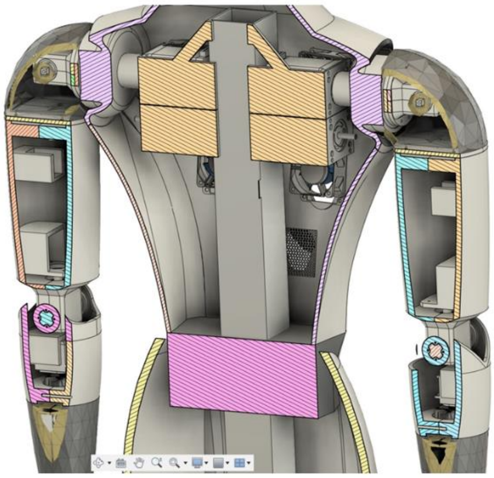

Figure 6: Open View of Chassis

The humanoid robot receives complete evaluation by running simulation tests which adopt Gazebo simulation environment as their validation platform. The movement characteristics of the digital robot representation evaluate its behavior through various operational conditions. Autonomous navigation evaluation occurs through the testing environment which merges sensor fusion algorithms between LiDAR and IMU and encoder information. The research team implemented virtual simulations that featured industrial buildings and office areas with real barriers while including various floor types and moving agents including people and robots to test the robot system.

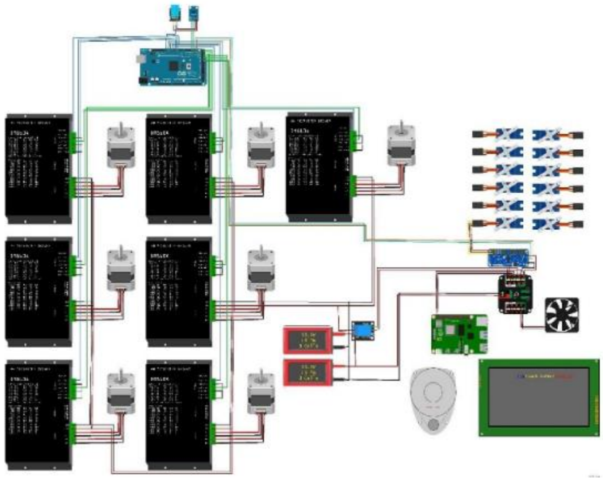

Figure 7: Electronic Circuit For Arm Development

A* and Dijkstra's algorithm have been implemented to execute path planning operations for determining optimal navigation pathways while concurrently providing obstacle clearance possibilities. IK solutions help establish the exact operational performance levels of the humanoid arm when working with objects. Gazebo's physical engine conducted performance tests of torque requirements and joint stresses and power usage to boost the robot for potential real-world use. These virtual frameworks permit knowledge discovery that allows development of improved motion control methods along with technological enhancements for energy efficiency.

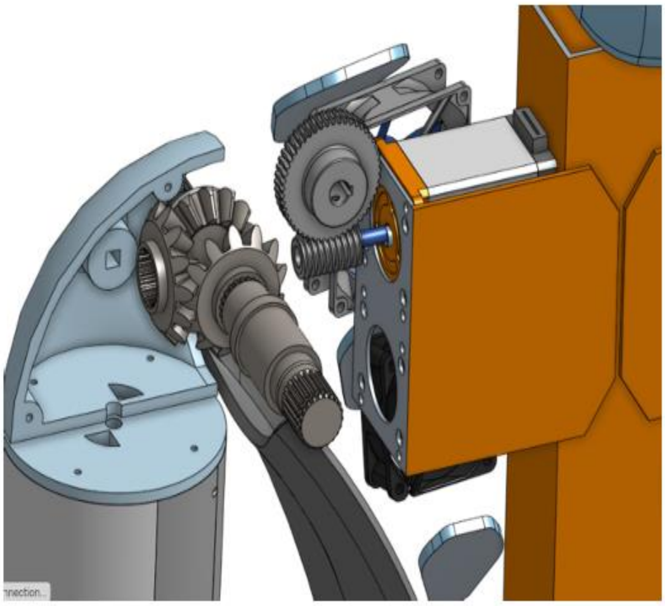

Figure 8: Gear Movement of the Shoulder

Results & Conclusions :

1. Successful Demonstration: The humanoid robot showcased autonomous navigation capabilities.

2. Sensor & Algorithm Integration: Efficient movement was achieved using advanced sensors and navigation algorithms.

3. Obstacle Detection & Adaptability: The robot effectively detected and avoided obstacles, adjusting its path dynamically.

4. Humanoid Features: Precise limb movement and posture enhanced interaction potential.

5. Real-World Applications: Suitable for healthcare, entertainment, and service industries.

6. Areas for Improvement: Needs better power efficiency and adaptability in complex environments.

7. Future Work: Focus on design refinement and capability expansion for broader use.

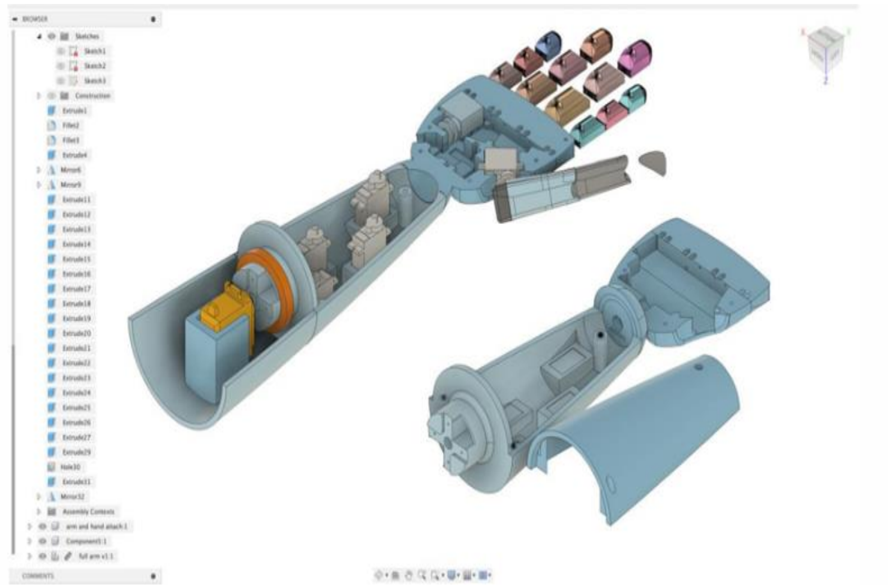

Fig.9. Design of robotic arm for the proposed humanoid robot

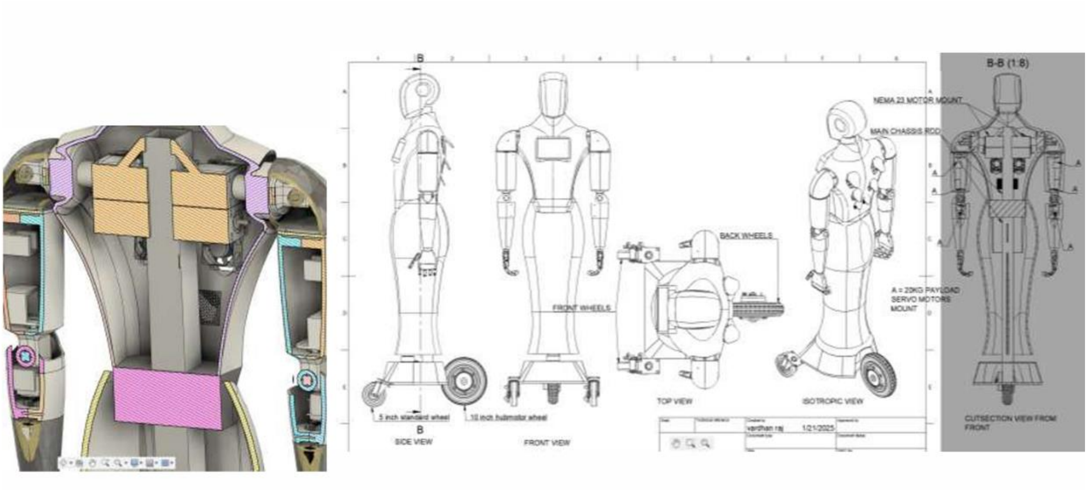

Fig.10. CAD designs of Humanoid Robot

Additional Testing: -

Figure 11: Testing Model of Humanoid Hand

The developers conducted various tests on the humanoid upper body prototype. The right arm prototype that includes worm gear and bevel gear-based shoulder 25 mechanism underwent torque and load testing for efficiently performing multi axis articulation. A verification process demonstrated how the wrist and elbow systems controlled by dual servo shafts achieved accurate angular positions during tests while string-actuated fingers operation demonstrated efficient grasping capability under multiple load scenarios through individual servo control. The re searchers assessed the 2-axis servo-driven neck mechanism to evaluate its smooth neck movements that accurately replicated different facial expressions.

The real-time processing and LiDAR sensor and IMU encoder and motor con troller interfacing used NVIDIA Jetson Orin as electronics and software platform. The scientists employed Gazebo simulation environment extensively to study the robot’s autonomous movement behavior and self-navigation functions with obstacle detection. The ROS-based control algorithms tested the navigation stack to validate proper sensor-input to actuator-output integration. A validation process based on Jacobian-based control allowed verification of how humanoid arm joint angles generated proper end-effector positions during inverse kinematics simulations.

Figure 12: Gazebo Simulation

Thorough testing and analysis established the assessment of the humanoid robot regarding its structural elements and movement systems and control frameworks. Testers evaluated the 14-inch powered wheel base system along with the front stabilizer wheel under different environment conditions across diverse load distributions when operating on inclines. The worm gear motor-based steering mechanism controlled the robot precisely due to its ability to maintain less than 2° steers from intended path trajectories. Real-time control accuracy was stable during operations through the encoder-based feedback system thus increasing navigation efficiency.

Figure 13: Final Phase of Humanoid Robot

During the testing phase scientists examined upper body and humanoid arm mechanisms specifically for their joint movements alongside torque strength and their ability to achieve the right body positions. The dual-axis motion of the shoulder joint attained high torque efficiency through its worm gear and bevel gear com bination which produced little backlash effect. The elbow and wrist joints that used dual-shaft servo motors achieved smooth movement and precise positioning through 0.5° angular step resolution. The fingers with string-driven controls per formed different force control tasks that showed versatility for handling objects.

Project Outcome & Industry Relevance :

The project successfully resulted in the design and development of a functional humanoid robot with autonomous navigation capabilities. By integrating various sensors and control algorithms, the robot is capable of detecting obstacles, planning optimal paths, and navigating through environments with minimal human intervention. This contributes significantly to the fields of robotics and mechatronics, offering hands-on insights into real-time systems, sensor integration, and motion planning.

In terms of industry relevance, such a humanoid robot has potential applications in multiple sectors. In healthcare, it could assist with patient interaction, elderly care, or basic medical tasks. In the service industry, it could serve as an information guide or perform delivery tasks in public spaces like malls or airports. The project also aligns with current trends in automation and artificial intelligence, making it a valuable prototype for industries aiming to develop human-assistive robotic systems.

Additionally, the skills and methodologies used in this project reflect industry standards, preparing the students for careers in advanced robotics and automation.

Working Model vs. Simulation/Study:

This project involved the development of a physical working model**.** A fully functional humanoid robot was designed, fabricated, and programmed to perform autonomous navigation using real-time sensor data and control systems. The robot was built using components such as Raspberry Pi 4**,** Arduino Nano**,** servo motors for limb movement**,** ultrasonic sensors**,** and a LiDAR module for mapping and obstacle detection. The integration of these hardware components was supported by software tools like ROS 2 Humble for navigation and control. This hands-on approach enabled real-world testing and validation of system performance, setting it apart from purely simulation-based or theoretical studies.

Project Outcomes and Learnings:

The key outcome of this project was the successful development of a humanoid robot capable of autonomous navigation in a controlled environment. The robot demonstrated effective obstacle detection, path planning, and real-time movement using integrated sensors and embedded systems. The project showcased the practical implementation of interdisciplinary knowledge in robotics, mechatronics, and control systems.

Through the process of designing, implementing, and analyzing the project, the team gained hands-on experience in hardware integration, circuit design, embedded programming, and system debugging. We also developed a deeper understanding of ROS 2 framework, sensor fusion, and real-time navigation algorithms. Additionally, the project enhanced our skills in teamwork, problem-solving, and project management—critical competencies for both academic and industrial careers in robotics and automation.

Future Scope :

- **Enhanced Navigation Algorithms:** Future work will involve improving the robot's navigation algorithms to handle more complex and dynamic environments. Incorporating machine learning could enable the robot to learn and adapt to new surroundings, increasing its versatility.
- **Energy Efficiency:** Optimizing the power consumption of the robot is a key goal. Implementing energy-efficient components and exploring new battery technologies could extend the robot's operational time, making it more practical for extended use.
- **Improved Human-Robot Interaction:** Incorporating advanced voice recognition and natural language processing (NLP) could improve communication between the humanoid robot and humans, enabling more intuitive and effective interaction.
- **Integration with IoT:** By connecting the humanoid robot to the Internet of Things (IoT), it could share data and interact with other devices or systems, enhancing its functionality for applications like home automation or healthcare monitoring.
- **Expanded Applications in Healthcare:** Further development could enable the robot to assist with more specialized healthcare tasks, such as providing support for elderly care, aiding mobility for patients, or performing basic medical checks.
- **Autonomous Learning and Decision Making:** The robot could be enhanced with autonomous decision-making capabilities, enabling it to perform tasks with minimal human input, improving its efficiency and broadening its scope of use in various industries.