REX

The Self-Navigating AI-based Quadruped Robot

Background

The field of robotics has witnessed remarkable advancements in recent years, with robots becoming increasingly capable of performing a wide range of tasks, from manufacturing and healthcare to exploration and search and rescue missions. One particularly fascinating area of development is the creation of self-navigating quadruped robots, which combine the agility of four-legged locomotion with the intelligence of AI-based navigation systems. These robots represent a significant breakthrough in robotics, offering unprecedented versatility in navigating complex and dynamic environments.

Traditionally, robots have been restricted to controlled and structured environments, limiting their applications. However, the emergence of self-navigating AI-based quadruped robots opens up new possibilities across various domains. These robots can autonomously traverse challenging terrains, adapt to unforeseen obstacles, and perform tasks in real-world scenarios, making them invaluable tools for industries ranging from agriculture and construction to disaster response and space exploration.

Introduction

The concept of self-navigating AI-based quadruped robots revolves around creating autonomous robotic systems that mimic the biomechanics of quadruped animals while harnessing the power of artificial intelligence to perceive and interact with their surroundings. These robots employ a combination of advanced sensors, machine learning algorithms, and robust mechanical designs to achieve unparalleled mobility, adaptability, and intelligence.

By imitating the gait and movement patterns of animals like dogs or cheetahs, these robots have the potential to revolutionize various industries and applications. They can access remote or hazardous locations that are difficult for traditional wheeled or tracked robots, making them ideal for tasks such as inspecting infrastructure, monitoring wildlife, assisting in search and rescue operations, and aiding in space exploration missions.

Scope

The scope of research and development in the field of self-navigating AI-based quadruped robots is broad and multidisciplinary. It encompasses various aspects of robotics, artificial intelligence, biomechanics, and sensor technology. Some key areas within this scope include:

1. Mechanical Design:

Developing and optimizing the physical structure of quadruped robots to ensure stability, agility, and energy efficiency. This includes advancements in materials, actuation systems, and locomotion mechanisms.

2. Sensory Perception:

Integrating a diverse range of sensors, including cameras, LIDAR, IMUs (Inertial Measurement Units), and environmental sensors, to enable robots to perceive and understand their surroundings in real-time.

3. AI and Machine Learning:

Implementing sophisticated AI algorithms to process sensor data, make real-time decisions, plan optimal paths, and adapt to dynamic environments. Machine learning techniques are crucial for training robots to navigate and interact autonomously.

4. Autonomous Navigation:

Developing robust navigation algorithms that allow robots to autonomously explore, map, and navigate in complex, unstructured, and unpredictable environments while avoiding obstacles and hazards.

5. Human-Robot Interaction:

Exploring ways to make these robots safe and user-friendly for human collaboration, including natural language interfaces, gesture recognition, and haptic feedback.

Applications

Identifying and addressing specific industry applications, such as:

- Construction and Inspection:
  Robot dogs can navigate challenging construction sites and perform inspections of structures, helping to improve safety and efficiency by assessing structural integrity and identifying potential issues before they escalate.

- Oil and Gas:
  They can be used for remote inspections of pipelines and oil rigs, reducing the need for human workers in hazardous environments. These robots can access hard-to-reach areas to monitor equipment and detect leaks or faults.

- Agriculture:
  Robot dogs can assist with various agricultural tasks, including crop monitoring, animal herding, and autonomous weeding. Their agility allows them to move through fields while collecting data on crop health or assisting with livestock management.

- Public Safety:
  They can be deployed for search and rescue operations in disaster-stricken areas, using their mobility and sensors to locate and aid survivors. Additionally, they can be used for monitoring public spaces to enhance security and surveillance capabilities.

- Warehousing and Logistics:
  Robot dogs can help with inventory management, material transportation, and order fulfillment in warehouses and distribution centers. They can efficiently navigate storage facilities, making logistics operations more streamlined and cost-effective.

- Healthcare:
  In healthcare settings, robot dogs have potential applications such as delivering medical supplies within hospitals or assisting with patient care, such as providing companionship to patients in long-term care facilities.

- Entertainment and Events:
  Robot dogs can be used for entertainment purposes, such as interactive exhibits in museums, theme parks, or live events. Their lifelike movements and interactions can create engaging and memorable experiences for visitors.

- Environmental Monitoring:
  Equipped with a variety of sensors, robot dogs can monitor environmental conditions in remote or sensitive areas. They can track wildlife, collect data on air and water quality, and aid in conservation efforts by providing valuable research insights.

- Mining:
  In mining operations, robot dogs can assist with safety inspections, mapping, and data collection in underground or remote areas where human access is limited or risky. They can help ensure the safety and efficiency of mining activities.

- Military and Defense:
  Robot dogs can be utilized for reconnaissance and surveillance purposes in military operations. Their ability to navigate rough terrains and provide real-time data makes them valuable assets for assessing potential threats and gathering intelligence in the field.

Test Case

In this test case, we plan to develop a Self-Navigating AI-based Quadruped Robot called " **REX** ", who will be tasked with performing multiple responsibilities towards the FAST NU University, Lahore Campus. Few of those possible responsibilities are mentioned below:

- Night Security
  Rex will perform night dog duties and provide alert in case of intrusion in the campus

- Temperature Mapping
  Rex will provide a temperature map of the campus so that the management may know which areas of the building are either extremely hot in the summers or extremely cold in the winters and make necessary precautions.

- Lost and Found
  Rex will aid in Lost and Found items by detecting any unattended item and uploading/registering its location to the University Database.

- ### Student Discipline Regulation

  Rex will help in monitoring the students and providing alert in case students are involved in actions such as vaping or smoking in campus premises especially in the washrooms.

- ### Misfunction Detection

  Rex will help in timely detection of any misfunction of University Equipment such as ACs, Lights, Projectors, Circuit Boards.

- ### Disaster Detection

  Rex will help in timely detection of disasters such as Fire, Water Leakage, Naked Electrical Wires, Fainted Students or Injured Students

- ### Navigation of Campus

  Rex will guidance any visitors such as parents or students from the Main Gate or any point within the university to reach a desired destination in the university such as administration office, Student center, Admission Office etc.

Methodologies and Approaches

They are as follows:

1. Design Details

   - REX's design draws inspiration from nature, featuring adaptive feet design, leg structure, shoulder joint, and a serpentine tail.
   - The body structure has been optimized for easy access to internal components, including the newly added sensors.

2. Modules

   REX comprises several modules:

   - The Map module detects room boundaries.
   - The Camera module performs edge detection.
   - The Sonar module handles object avoidance.
   - The Stabilize module monitors sensor readings.
   - The Display Map module visualizes room boundaries.
   - The Pressure will detect any change in pressure of room
   - The Humidity module will detect the Humidity for the atmosphere
   - The Heat Module will help construct the heat map of the building
   - The Light Module will help in differentiating between day and night
   - The IR Module will help detect any case of fire or hazardous substance.
   - The Cloud module will exchange data and instructions from the cloud

3. Operation

- The robot operates in different modes: demo, explore, and navigate, using command-line inputs.
- The main module oversees execution, generates maps and instructs in performing the necessary actions.

4. Experimental Results

- Experiments demonstrated REX's capabilities, such as environment mapping, obstacle avoidance, and enhanced environmental awareness.
- The robot's quadrupedal locomotion enabled smooth and efficient movement.

Manufacturing

❖ Software Used

1. **Blender:**
   Used for the initial 3D prototype design of REX, including its exoskeleton and structural integrity testing.

2. **Free CAD:**
   Planned for designing a scale model of REX for final production.

3. **Webots:**
   Intended for virtual testing of the robot's structural integrity and design features.

4. **ROS (Robot Operating System):**
   Employed for managing hardware abstraction, device drivers, communication between processes, and more, enhancing the robot's capabilities.

❖ Hardware Devices Used

1. Stereo Camera

   - Function: Used for mapping the environment and providing depth information.

   - Specifications:

     - Weight: Approximately 200 grams.
     - Power Consumption: Consumed approximately 5 watts of power during operation.
     - Resolution: Provided a high-resolution stereo image for accurate depth perception.
     - Environmental Sensitivity: Affected by lighting conditions and reflections, leading to potential errors in the generated map.

2. Sonar Sensor

   - Function: Implemented for object avoidance and obstacle detection.

   - Specifications:

     - Weight: Lightweight, approximately 50 grams.
     - Power Consumption: Minimal power usage, typically less than 1 watt.
     - Range: Capable of detecting objects at distances of up to 5 meters.
     - Environmental Adaptability: Effective in most environmental conditions, with occasional limitations in areas with high noise or sound interference.

3. Raspberry Pi

   - Function: The core computing platform responsible for processing data and executing control commands.

   - Specifications:

     - Weight: Raspberry Pi 4 Model B weighs around 50 grams.
     - Power Consumption: Typically consumes 2.7-3.0 watts of power.
     - Processor: Quad-core ARM Cortex-A72 CPU, offering sufficient computational power.
     - Operating System: Raspbian OS, providing a user-friendly interface.

4. Servo Motors

   - Function: Used in the shoulder and tail joints to enable three-dimensional mobility.

   - Specifications:

     - Weight: Varies based on servo model, typically 50-100 grams per servo.
     - Power Consumption: Generally, consumes 4-6 watts per servo.
     - Degrees of Freedom (DoF): Configured to provide a wide range of motion, allowing the robot to move like a joystick.
     - Control: Controlled via PWM signals, offering precise positioning.

5. Wiring and Connectors

   - Function: Used for connecting various components and sensors.

   - Specifications:

     - Weight: Negligible compared to other components.
     - Power Consumption: Minimal power usage, mainly for signal transmission.
     - Reliability: Properly insulated and secured to prevent wear and tear.

6. Li-Po Battery

   - Function: Power source for the robot's components and motors.

   - Specifications:

     - Weight: Varies based on capacity, typically 100-300 grams.
     - Capacity: Chosen capacity is [insert capacity] mAh for extended operation.
     - Voltage: Provides the necessary voltage levels for motor and component operation.
     - Charging: Equipped with a charging circuit for easy recharging.

7. Ball and Socket Joints

   - Function: Essential components in the foot and tail structure for articulation and stability.

   - Specifications:

     - Weight: Lightweight, typically less than 50 grams per joint.
     - Material: Made from durable materials like plastic or metal.
     - Articulation: Provides a wide range of motion for feet and tail movement.
     - Spring Mechanism: Incorporated to allow joints to snap back to their original position.

8. Exoskeleton and Structural Components

   - Function: Forms the robot's body and provides support for other components.

   - Specifications:

     - Weight: Total weight of the robot is approximately [insert weight] grams.
     - Material: Typically constructed from lightweight and durable materials such as plastic or aluminum.
     - Structural Integrity: Designed to withstand mechanical stresses and environmental conditions.
     - 3D Printing: Components may be 3D printed for cost-effectiveness and customization.

9. Webots Virtual Environment

   - Function: Used for testing the robot's performance and behavior in a simulated environment.

   - Specifications:

     - Platform: Cross-platform compatibility for Linux, Windows, and macOS.
     - Realistic Simulation: Provides a realistic physics engine for accurate testing.
     - Sensor Emulation: Allows emulation of sensors, including the stereo camera and sonar sensor.

10. Inertial Measurement Unit (IMU)

    - Function: Used for.

    - Specifications:

        - Platform:

Additional:

1. Light Sensor: Included to detect ambient light levels and adapt robot behavior accordingly.
2. Heat Sensor: Used to detect temperature variations in the environment.
3. Humidity Sensor: Monitors humidity levels for enhanced environmental awareness.
4. Pressure Sensor: Provides data on atmospheric pressure changes.
5. Infrared (IR) Sensor: Enables object detection and tracking based on heat signatures.

❖ Construction Restraints

- **KEEP THE TOTAL WEIGHT UNDER 20 KG:**
  Current Weight:
  2 KG (Sensors) + 7 KG (Exoskeleton) = 9 KG

- **BE SURE TO TAKE ALL ENVIORNMENT FACTS TO CONSIDERATION**
  Currently under assessment

- **REINFORMCE THE JOINTS TO REDUCE RISK OF FAILURE**
  Currently under assessment

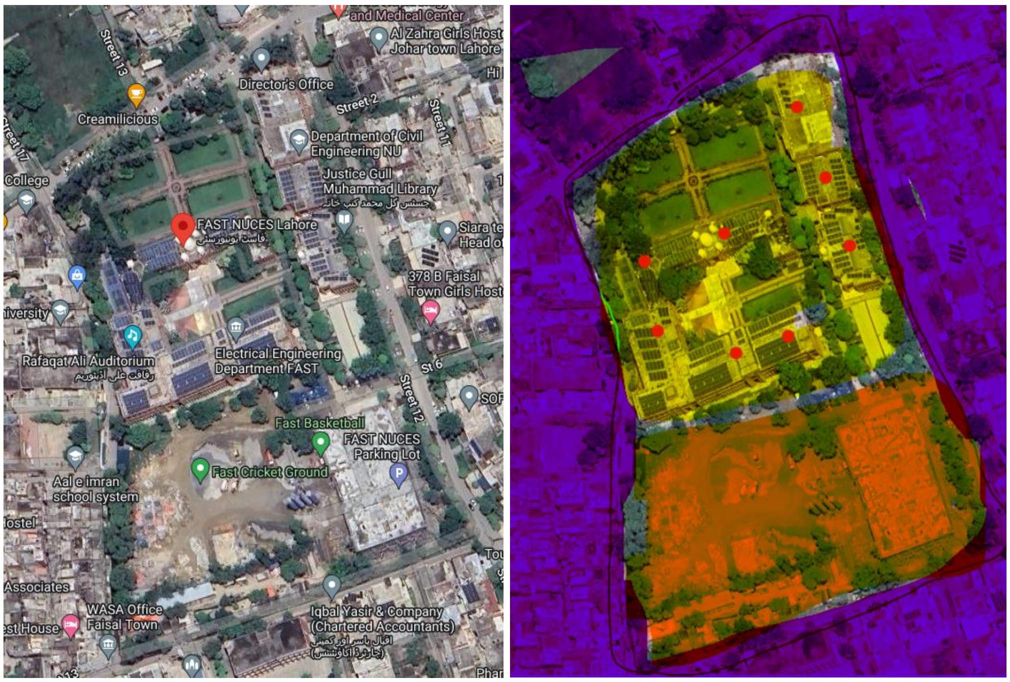
- **CONNECTIVITY TO CLOUD IS CRUTIAL**
  Currently under assessment

❖ Cloud Connection Points

University Field Map as well as the location of the wifi points.

The Highlighted Yellow Region shows where the connention will be the strongest.

The Highlighed Red Region shows where the connection will not be possible.



Project Cost Estimation

Project Completion Time Estimation

Full-Scale Deployment