Grenze International Journal of Engineering and Technology, January Issue

Campus Guardian: An Autonomous Monitoring Robot

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***Abstract*— The Campus Guardian is an intelligent robotic system designed to enhance campus navigation, security, and user engagement through robotics and IoT technologies. It features infrared (IR) sensors for line-following and step-counting, ultrasonic sensors for proximity detection, and a Human-Machine Interface (HMI) for interactive user experiences. The robot autonomously navigates predefined routes, ensuring accurate movement and obstacle avoidance, while the HMI allows users to select destinations, access campus information, and view multimedia content. Key functionalities include real-time step counting to provide actionable insights for campus management and resource optimization. The ultrasonic sensor enhances interactivity by activating the HMI upon detecting user presence, offering a seamless and engaging experience. Designed for modularity, the system is easily adaptable for use in malls, hospitals, or airports, providing scalable solutions for diverse environments. Future developments include GPS integration for outdoor navigation, multilingual HMIs, and advanced analytics for step-count data. Rigorous testing confirms its reliability in navigation, interaction, and data collection, positioning Campus Guardian as an innovative solution for transforming campuses into smart, automated spaces that prioritize accessibility and efficiency.**

Keywords— Campus monitoring, autonomous robot, IR sensors, ultrasonic sensors, motion detection, multi-sensor approach, HMI, Line follower.

I. Introduction

Modern university campuses serve as bustling hubs of academic, administrative, and social activities. Managing these dynamic spaces effectively requires innovative solutions that address navigation, security, and the dissemination of information to diverse users, including students, staff, and visitors. Traditional tools such as static maps, signboards, and human guides are often insufficient in meeting the evolving needs of large and interconnected campuses. These conventional methods lack real-time interactivity and adaptability, leading to inefficiencies and an inconsistent user experience.

The Campus Guardian project proposes a transformative approach by introducing a smart, autonomous robotic system designed to bridge these gaps. At its core, the robot features infrared (IR) sensors for precise line-following navigation and ultrasonic sensors for detecting nearby individuals. Together, these sensors ensure seamless movement across predefined routes, such as from an Admin Office to an Accounts Section, while preventing collisions with obstacles in dynamic environments.

The system is further enhanced by a Human-Machine Interface (HMI) that acts as an interactive medium between the user and the robot.

Grenze ID: 01.GIJET.11.1.561

The HMI enables users to select destinations, access vital campus information, and even view multimedia content such as promotional videos or event updates. This personalized interaction improves user engagement, making campus navigation more intuitive and enjoyable. In addition to serving as a navigation tool, the Campus Guardian contributes to campus management by incorporating step-counting capabilities. Using IR sensors, the robot tracks entry and exit foot traffic, generating data that can assist in resource allocation and space optimization. This dual functionality of enhancing user convenience and providing actionable data for administrators underscores the robot’s holistic value.

II. Literature Survey

The authors Y. Liu and J. Lan in [1] presents an advanced optimization model for securing campus networks, using real-time threat detection, Intrusion Prevention Systems (IPS), encryption, and Role-Based Access Control (RBAC) to protect sensitive data. The scalable, modular system adapts to various campus environments, ensuring cost-effective integration. Rigorous testing shows its efficiency in identifying threats, maintaining operational stability, and offering actionable insights, highlighting the importance of intelligent security frameworks in modern campuses.

The authors A. A. Oke and O. V. Matthews in [2] explore the use of wireless, semi-autonomous robots for campus security, equipped with PTZ (Pan-Tilt-Zoom) cameras, differential wheels, two-way audio, and remote control for flexible monitoring. The system addresses challenges like connectivity, power management, and cyber threats. It offers a scalable, cost-effective alternative to traditional security, with potential applications in other sectors. Future enhancements could include autonomous patrolling and facial recognition, improving safety and reducing human labour.

The authors T. Narendrakumar and A. S. Pillai in [3] discuss the adaptation of IoT technologies for creating a smart connected campus, integrating real-time sensing, remote control, and data management. Key features include the Campus Info mobile app, smart canteen management, and monitoring of resources like water and temperature. The system enhances operational efficiency, sustainability, and user convenience. Its modular design allows scalability, demonstrating the potential of IoT to improve campus accessibility, resource optimization, and management.

The author Theodoros Anagnostopoulos in [4] presents a spatiotemporal authentication system for smart campuses, using location and time-specific data to enhance security. Unlike traditional methods, it reduces risks from stolen credentials by leveraging contextual information. The system integrates with existing biometrics for multi-factor authentication, improving security and user experience. Its scalability makes it suitable for broader applications, highlighting the potential of spatiotemporal data in creating more robust, context-aware authentication systems.

The authors B. Gadgay, D. C. Shubhangi and R. Abhijeet in [5] present an IoT-enabled surveillance system using a four-wheeled autonomous robot with path-tracking and ESP CAM 8266 for real-time monitoring. RFID technology controls access to restricted areas and logs entry/exit data. The system reduces human error, improves unauthorized activity detection, and stores data in the cloud for real-time monitoring. This scalable, cost-effective solution enhances campus security and resource management through automation.

III. Methodology

- Initialization: The system begins by initializing all its hardware and software, calibrating IR sensors for path and presence detection, testing ultrasonic sensors for proximity, and setting motors to neutral. The HMI is verified through test menus to ensure functionality. This preparatory phase ensures all components are operational, establishing a stable foundation for the robot's tasks.
- Main Loop: After initialization, the robot enters a continuous monitoring loop, using IR sensors to detect user presence and trigger the ultrasonic sensor to measure distance (10 cm). If a user is within range, the system activates the HMI for interaction. This loop keeps the robot responsive while conserving energy when idle.
- HMI Activation: When a user is detected, the HMI interface activates, lighting up the touchscreen and displaying a menu with options like "Admin," "Accounts," or "Campus Info," which include maps, schedules, or multimedia. Designed for accessibility, it offers to help users navigate through the campus based on their destination, ensuring a seamless and user-friendly interaction.
- User Input: The user selects an option from the HMI menu, such as choosing a specific destination. This input is transmitted to the Raspberry Pi for processing, which determines the robot’s subsequent actions.

- Navigation Command: The robot calculates the best path based on the user's selection and uses IR sensors for line-following navigation. Motor drivers adjust speed and direction, while ultrasonic sensors detect and avoid obstacles. IR sensors also track step-count data as users move through areas, enabling real-time monitoring of campus traffic.
- HMI Update During Movement: While the robot moves, the HMI stays active and responsive. The ultrasonic sensor monitors user proximity, allowing the HMI to update with relevant information, like virtual tours or promotional videos, if the user is nearby. This feature enhances user engagement, reinforcing the robot's role as an informative guide.
- End of Interaction: Upon reaching the destination, the robot stops and displays a "Thank You" message on the HMI, signalling the conclusion of the session. The polite end-of-session message enhances user satisfaction and concludes the interaction on a positive note.

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START

// Step 1: User Detection
WHILE system is running:
  Read data from IR sensor to detect presence of users
  IF user is detected:
    Read data from Ultrasonic sensor to determine user proximity
    IF user is within defined range (e.g., 1 meter):
      Proceed to Step 2
    ELSE:
      CONTINUE scanning for users

// Step 2: HMI Activation
IF user is detected within range:
  Activate HMI screen
  Display options (Admin, Accounts, Campus Info, etc.) on HMI

// Step 3: User Input
WAIT for user input (select desired option: Admin, Accounts, etc.)
IF user selects an option:
  Capture user input on HMI
  Send selected option to Raspberry Pi for processing
  Proceed to Step 4

// Step 4: Navigation Command
IF input received from user:
  Determine selected destination (Admin, Accounts, etc.)
  Use path planning algorithm to calculate the best route to the destination
  Communicate with motor drivers to initiate movement toward destination
  Start robot movement and navigation using motors and sensors

// Step 5: Data Logging (Step Count)
WHILE robot is moving:
  Continuously monitor IR sensors to count steps
  Track entry and exit steps as the robot moves through different areas
  Log the step count data to the data logging module

// Step 6: HMI Update (Campus Info)
WHILE robot is moving:
  Continuously check user proximity using Ultrasonic sensor
  IF user is within range:
    Update HMI to show campus-related information (videos, announcements, etc.)
    Display relevant content for the user

// Step 7: End of Interaction
IF robot reaches destination:
  Stop robot movement
  Display a "Thank you for using the system!" message or other relevant information on HMI
  Log destination and step count data for admin review

// Step 8: Admin Data Review
Admin can access logs through the Admin Dashboard
Admin can view step count data, monitor robot movements, and review system performance

WAIT for next user interaction

END
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Fig 3.1: Working Algorithm

IV. Results

The Campus Monitoring Robot integrates multiple sensors and systems to create a comprehensive and effective solution for automated campus navigation, information dissemination, and step-count tracking. After testing and evaluation, the results indicate that the system functions as intended, with a few areas for optimization.

- Navigation and Path Following: The robot effectively uses IR sensors for path following, accurately detecting black lines to guide its movement. During testing, the robot consistently followed the pre-defined path when placed on the black line, making real-time adjustments based on sensor input. The integration of the IR sensor with the motor driver allowed for smooth and responsive movement.
- Ultrasonic Sensor and Proximity Detection: The ultrasonic sensor performed effectively in detecting obstacles and persons within its range, triggering the HMI interface as expected. When a person came within the detection range (10 cm), the sensor successfully activated the HMI, displaying campus information or videos.
- HMI Functionality and User Interface: The HMI displayed options such as "Admin" and "Accounts" as expected, allowing the user to select the desired location. The interface was clear, and navigation was easy. Additionally, the robot displayed relevant campus information or videos when a person approached within range.
- Step Counting System: The step counting mechanism worked as expected, logging the entry and exit steps accurately. The robot tracked the number of steps taken during entry and exit to a specific campus area, providing the required data for tracking purposes.

➢ Motor Control and Navigation Response: The motor driver responded correctly to movement commands, such as "move forward," "stop," and "turn." The robot's movement was smooth, with no significant delays or misalignment when following the path dictated by the IR sensor or the user commands.
➢ System Integration and Overall Functionality: The system integration tests showed that all individual components—IR sensors, ultrasonic sensors, HMI and motors—worked together seamlessly. The robot navigated, interacted with users, and logged step counts without significant issues. The integration of various modules was effective in creating a functional, autonomous robot.

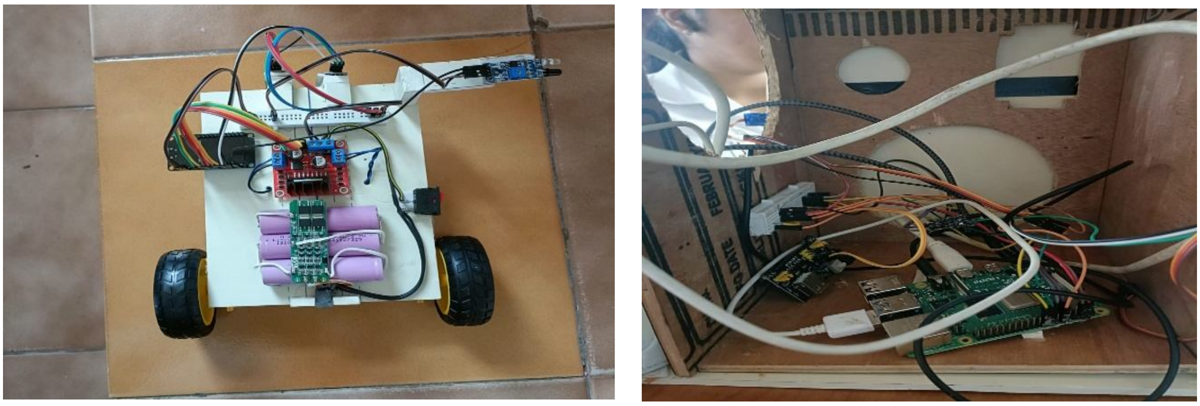

Fig 4.1 Working Model

V. Conclusion and Future Scope

The Campus Monitoring Robot is a groundbreaking solution that enhances campus operations by integrating advanced technologies like IR sensors for block detection, ultrasonic sensors for precise proximity sensing, and a Human-Machine Interface (HMI) for seamless user interaction. The robot autonomously navigates predefined campus routes, providing real-time information such as campus maps, event schedules, and multimedia content to engage users. Its step-counting feature tracks entry and exit movements, offering campus administrators valuable insights into footfall patterns, which aids in resource planning and space utilization. The robot’s modular design ensures scalability and adaptability, making it suitable for use in corporate offices, hospitals, and public venues. With real-time data processing, it operates efficiently even in dynamic environments, aligning with modern sustainability goals through eco-friendly, cost-effective hardware. In terms of campus security, the robot replaces manual methods with an automated, intelligent solution, offering flexibility, cost-effectiveness, and scalability. Its modular design ensures future expansions, enabling the robot to meet growing campus safety demands.

The future scope of the robot includes advancements like AI and machine learning for predicting user movements and adapting to changing environments. Integrating GPS and SLAM (Simultaneous Localization and Mapping) would extend its capabilities to outdoor spaces. Voice recognition and natural language processing (NLP) would enhance accessibility, while data analytics would provide insights into campus usage patterns. Adding surveillance cameras and facial recognition would improve security, transforming the robot into a security tool. Energy-efficient measures such as solar power and optimized motor usage would make it more eco-friendly. Furthermore, multi-robot coordination would enhance scalability for larger campuses, and the robot’s modular design allows its use in hospitals, malls, and smart cities. These improvements ensure that the Campus Monitoring Robot will continue to evolve as a key tool in smart campus infrastructure.

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