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HUMAN-TRAIL BOT: SMART HUMAN GUIDANCE ROBOT

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ABSTRACT

This project focuses on the development of a human-following robot, known as Human-Trail Bot, designed to autonomously follow a specific individual in indoor or outdoor environments. The system utilizes a BLE beacon attached to the user, which the robot detects and follows through a BLE receiver, ensuring that it stays close to the designated person. Ultrasonic sensors and IR sensor aid in obstacle detection, preventing collisions and enabling safe navigation through crowded or dynamic spaces.

To achieve accurate and responsive tracking, the project incorporates a Proportional-Integral-Derivative (PID) control algorithm, which adjusts the bot's speed based on the detected distance from the user, resulting in smooth and stable following behavior. Kalman filtering further refines the robot's positioning by filtering out noise from sensor readings, while RSSI filtering from the BLE signal improves the reliability of distance estimates between the user and the bot.

The fusion of these algorithms enables Human-Trail Bot to respond swiftly and accurately to the movements of the specific user, ensuring reliable operation in real-world scenarios. The results indicate that this system can maintain a consistent following distance, avoid obstacles effectively, and provide a robust solution for applications where hands-free following of individuals is required, such as in assistance robots and personal transport systems.

Keywords: Human-Following Robot, Iot Technology, BLE-Based Tracking, PID Control, Hands-Free Following, Personal Assistance Robot.

I. INTRODUCTION

The Human-Trail Bot is an advanced robotic system designed to autonomously follow a specific individual in both indoor and outdoor environments. The system leverages a BLE beacon, worn by the user, which the robot detects using a BLE receiver, ensuring it stays within a predefined range of the person. This enables the robot to maintain a consistent distance and follow the user without manual control.

To ensure safe and efficient navigation, the robot is equipped with ultrasonic sensors that help detect obstacles in its path, preventing collisions in dynamic environments. An IR sensor is also integrated to facilitate precise alignment and smooth movement, enhancing the overall tracking accuracy. This combination of sensors ensures that the robot can move autonomously in various settings without interruption.

The robot utilizes a Proportional-Integral-Derivative (PID) control algorithm to adjust its speed based on the detected distance from the user, resulting in responsive and stable following behavior. The PID algorithm enables the robot to maintain a consistent pace, providing a smooth experience for the user, even when the distance between them changes.

Additionally, Kalman filtering is applied to reduce noise from sensor readings and improve the robot's positioning accuracy. RSSI (Received Signal Strength Indicator) filtering is also used to refine the distance estimates between the user and the bot. The system operates on a state machine architecture, allowing the robot to switch seamlessly between various behaviors, such as following, avoiding obstacles, or entering idle mode. This approach ensures that the Human-Trail Bot operates efficiently in real-world scenarios, making it ideal for applications such as assistance robots and personal transport systems.

II. LITERATURE SURVEY

1. Human Following Robots Using BLE Technology

BLE technology is commonly used for human-following robots, where a beacon worn by the user transmits signals to the robot. Huang et al. (2015) showed that BLE-based tracking can estimate the user’s position using

RSSI values, though environmental factors can affect signal accuracy, requiring filtering techniques to improve performance.

2. Obstacle Detection and Avoidance Using Ultrasonic and Infrared Sensors

Ultrasonic and infrared sensors help robots detect obstacles and maintain a safe following distance. Sola et al. (2018) demonstrated how these sensors enable navigation in dynamic spaces by detecting obstacles and adjusting the robot's movement to avoid collisions.

3. PID Control Algorithms in Human-Following Robots

PID control algorithms adjust the robot's speed and position based on sensor feedback. Zhang et al. (2017) showed that PID control allows for consistent following distance by continuously adjusting velocity, though fine-tuning is required to achieve optimal performance across various environments.

4. Kalman Filtering for Sensor Data Smoothing

Kalman filters enhance sensor accuracy by reducing noise in measurements. Patel et al. (2016) demonstrated that applying Kalman filtering improves distance estimates from sensors, providing smoother and more accurate tracking in noisy environments.

5. State Machine Architectures for Robot Behavior Management

State machines enable efficient management of robot behaviors like following and obstacle avoidance. Miller et al. (2017) showed how state machines allow robots to adapt to their environment by switching between operational modes, ensuring robust performance.

6. Challenges and Future Directions in Human-Following Robots

Challenges like sensor calibration and obstacle detection still exist in human-following robots. Shao et al. (2019) highlighted the need for improved algorithms and sensor integration, with future trends focusing on machine learning, advanced sensors, and enhanced communication technologies like 5G.

III. METHODOLOGY

1. Required Components:

Arduino Uno R3, BLE Beacon and Receiver, Ultrasonic Sensors, IR Sensor, L293D Motor Driver and DC Motors, Lithium-Ion Battery

2. BLE Beacon and Signal Processing:

The Human-Trail Bot tracks the user by detecting signals from a BLE (Bluetooth Low Energy) beacon worn by the individual. The BLE receiver on the robot continuously receives these signals, allowing it to estimate the user's position.

RSSI (Received Signal Strength Indicator) filtering is applied to the BLE signal data to improve the accuracy of distance estimation, ensuring the robot maintains an appropriate following distance.

3. Sensor Integration for Obstacle Detection and Tracking:

Ultrasonic sensors detect obstacles in real time, enabling the bot to avoid collisions, and the IR sensor ensures precise alignment with the user's movement.

4. Control System and PID Algorithm:

The bot's speed is controlled via a PID (Proportional-Integral-Derivative) algorithm, adjusting movement based on distance from the user for stable and responsive tracking.

5. Data Filtering and Position Estimation:

Kalman filtering reduces noise and enhances distance accuracy, while RSSI filtering further refines position estimation for more reliable tracking

6. Path Prediction and Adjustment:

A path prediction mechanism anticipates the user's trajectory, enabling smoother adjustments and reducing sudden directional changes.

By continuously updating its route based on user direction and speed, the robot can minimize abrupt turns and maintain a stable following distance, even in fast-paced or crowded environments

7. Testing and Calibration:

Iterative testing is conducted to calibrate sensor accuracy, PID parameters, and system transitions, ensuring reliable performance across various environments.

Field tests are conducted to ensure the robot reliably follows the user in both open and confined spaces, with consistent obstacle detection and seamless mode switching.

8. Documentation and Finalization

Document hardware connections, software flow, algorithms, and deployment steps for future reference and potential improvements.

IV. HARDWARE DESCRIPTION

The Human-Trail Bot is designed with various hardware components that enable it to track and follow a specific person autonomously while avoiding obstacles. The key hardware components used in the project are as follows:

1. Arduino Uno R3 (Microcontroller)

The Arduino Uno R3 serves as the central processing unit of the Human-Trail Bot. It collects data from various sensors (BLE, ultrasonic, IR), processes this information, and controls the actuators (motors) based on programmed logic. The Arduino operates at 5V and has a clock speed of 16 MHz, suitable for real-time environmental monitoring and control of the robot's movement.

Voltage Range: 5V

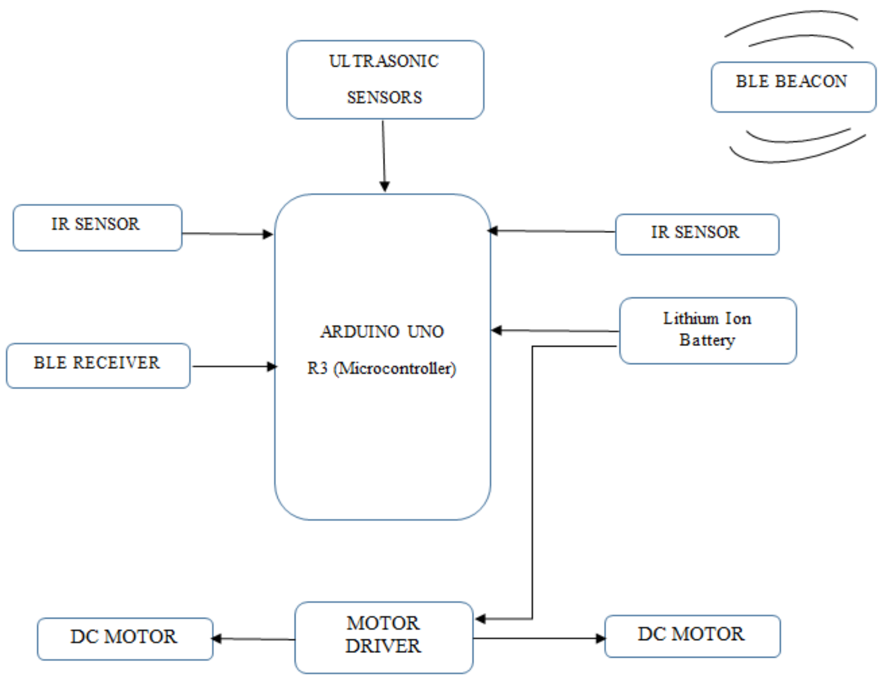
Current Consumption: 20-50 mA

2. Bluetooth Low Energy (BLE) Beacon

The BLE beacon is worn by the user and continuously transmits signals to the robot. The robot uses these signals to estimate the distance to the user and maintain a consistent following distance. The beacon's signal strength is measured via the robot's BLE receiver.

Voltage Range: 3V

Range: Typically, up to 100 meters (depending on environmental factors)



3. Ultrasonic Sensors (Obstacle Detection)

The ultrasonic sensors detect obstacles in the robot's path by emitting high-frequency sound waves and measuring their reflection time. These sensors help the robot avoid collisions by adjusting its movement when obstacles are detected in the environment.

Voltage Range: 5V

Range: 2 cm to 400 cm

Accuracy: ± 3 mm

4. Infrared (IR) Sensor (Alignment and Movement Control)

The IR sensor is used for precise alignment of the robot with the user and assists in smooth movement by detecting proximity to the user's body. It helps the robot follow the user at a constant distance and adjust its position for optimal tracking.

Voltage Range: 3.3V to 5V

Detection Range: 5 cm to 80 cm

5. DC Motors (Actuators for Movement)

The DC motors provide the robot's mobility, allowing it to move forward, backward, and turn. The motors are controlled by the L293D motor driver, which allows for precise control of motor speed and direction, enabling the robot to follow the user smoothly.

Voltage Range: 5V to 12V

6. L293D Motor Driver (Motor Control)

The L293D motor driver is used to control the DC motors by providing bidirectional control, enabling the robot to move in both directions (forward and backward). It receives commands from the Arduino and adjusts the motor's operation based on the robot's needs for navigation.

Voltage Range: 4.5V to 36V

Current Rating: 600mA per channel

7. Lithium-Ion Battery (Power Supply)

A lithium-ion battery powers the entire system, including the Arduino, motors, sensors, and other components. It provides sufficient energy for the robot to function continuously for extended periods. The battery is rechargeable and ensures portability.

Voltage Range: 7.4V

Capacity: 2200 mAh

V. SOFTWARE DESCRIPTION

1. Arduino IDE and C++ Programming

The software is developed using Arduino IDE with C++ programming language, leveraging its extensive libraries and real-time processing capabilities. The program controls the robot's behaviour by reading sensor data, calculating distances, and issuing commands to the motors based on the defined logic for following the user.

2. Human Following Algorithm

The central algorithm is designed to track the user by processing BLE signals. The distance between the robot and the BLE beacon is estimated using RSSI (Received Signal Strength Indicator) values, which helps maintain a consistent following distance. If the robot moves too close or too far from the user, the algorithm adjusts the robot's speed and direction accordingly. The algorithm also ensures the robot avoids obstacles and maintains a safe distance from the user.

3. Obstacle Avoidance Logic

The robot employs ultrasonic sensors to detect obstacles in its path. The obstacle avoidance algorithm processes the sensor readings to determine if an object is in the robot's path. If an obstacle is detected, the robot will stop, turn, or reverse to avoid collision. This system ensures safe operation in dynamic environments.

4. PID Control for Smooth Movement

The PID (Proportional-Integral-Derivative) controller is implemented to fine-tune the robot's speed and positioning. The PID controller adjusts the motor's speed in real-time to ensure the robot follows the user smoothly, responding quickly to changes in distance or direction. This feedback loop improves the system's accuracy and responsiveness.

5. IR Sensor Integration

The IR sensor helps the robot maintain proper alignment with the user. It detects the proximity of the user's body and ensures that the robot does not veer off track. The IR sensor is continuously monitored to adjust the robot's position for precise following behaviour.

6. Real-time Data Processing

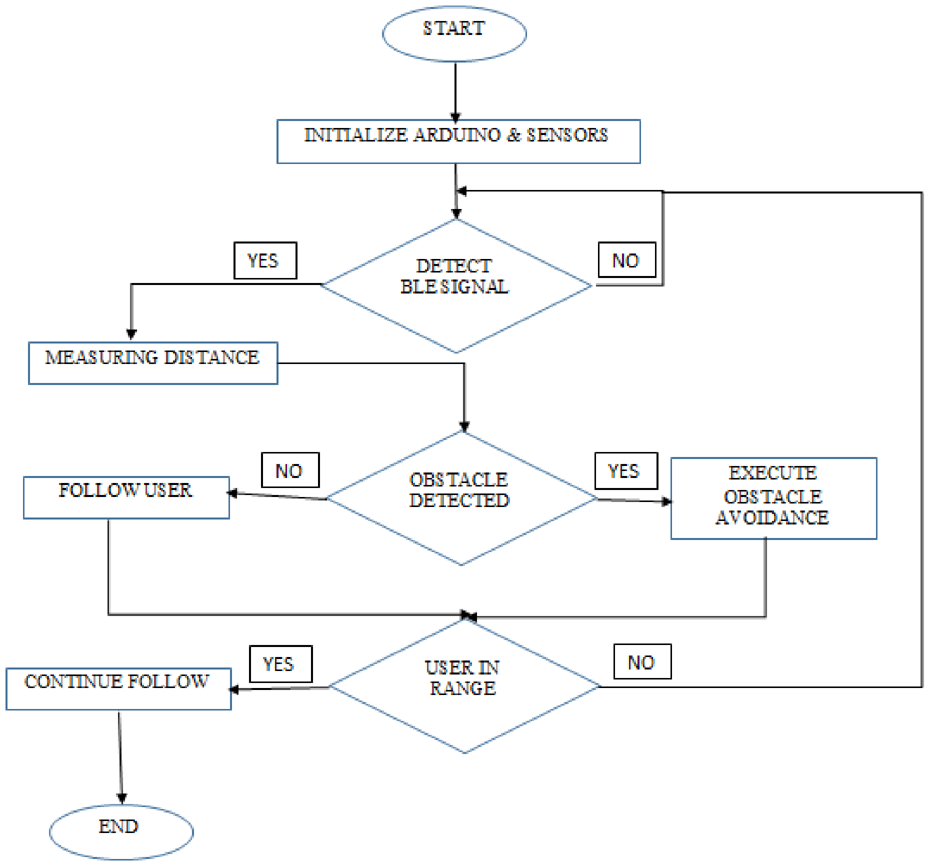
All sensor data, including BLE signal strength, distance measurements from ultrasonic sensors, and IR sensor feedback, is processed in real-time. The system uses interrupt-driven programming to ensure quick responses to sensor input, ensuring timely adjustments to the robot's actions.

VI. IMPLEMENTATION

The implementation of the Human-Trail Bot involves several crucial steps, starting with the physical assembly of hardware components. The Arduino Uno R3 microcontroller is connected to BLE, ultrasonic, and IR sensors, as well as a motor driver and motors, forming an integrated system capable of detecting, tracking, and following a user.

Once the hardware setup is completed, the software is programmed in the Arduino IDE using C++. The code handles data acquisition from sensors, processes the received signals, and adjusts motor speeds and directions for following or obstacle avoidance. The PID control algorithm, integrated within the software, fine-tunes the bot's response to maintain a consistent following distance.

Next, the system undergoes integration and testing to ensure that all components work cohesively. Initial tests focus on tracking performance, obstacle avoidance, and movement alignment with the user. After testing, the bot is ready for real-world deployment, where it follows a designated user and adapts to dynamic environments.



VII. CONCLUSION

The Human-Trail Bot project successfully demonstrates an autonomous, human-following robot capable of tracking a specific individual through BLE signal detection and ultrasonic sensing for obstacle avoidance. The integration of sensors, a BLE beacon, and PID control algorithm enables the bot to maintain a stable and responsive following distance. This robot has practical applications in hands-free assistance tasks, such as personal transport, support in warehouses, or as a smart shopping cart. Through real-time data processing and

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adaptive control, Human-Trail Bot achieves efficient navigation and user-following performance, even in dynamic environments. Future enhancements could include expanding the bot's adaptability for outdoor terrains and refining obstacle detection for complex surroundings.

Overall, Human-Trail Bot exemplifies a promising solution in assistive robotics, combining precision, flexibility, and functionality to meet the needs of modern, automated environments.

VIII. FUTURE SCOPE

1. Outdoor Navigation and GPS Integration: Expanding the bot's capabilities with GPS and outdoor tracking would enable it to follow users in open, outdoor spaces, broadening its use in areas like parks, campuses, and large retail spaces.
2. Advanced Obstacle Detection: Adding sensors like LiDAR or stereo cameras would improve the bot's ability to detect and navigate around complex obstacles, making it safer and more effective in crowded or dynamic environments.
3. Machine Learning for Adaptive Following: By incorporating machine learning, the bot could learn user movement patterns over time, enhancing its following accuracy and responsiveness in various real-world scenarios.

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