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Proximity-Based Autonomous Navigation and Transportation Robotic System

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Abstract
The creation of a completely autonomous and dependable mobile robot for collaboration continues to be a major area of academic interest as human–robot collaboration becomes more common in real-world applications. Collision-free navigation is one of the most important problems in this field, especially in unstructured settings with moving objectives and unknown obstacles. In order to allow a robot to autonomously navigate toward a moving target human while avoiding obstacles, this article introduces a cognitive robotic system (CRS). In order to guarantee obstacle avoidance and successful target tracking, the CRS's cognitive agent which is based on the Soar cognitive architecture evaluates the robot's current circumstances and decides what to do. Furthermore, a speed planning module creates appropriate linear and angular velocities to regulate the robot's motors using the dynamic window approach. A differential drive wheel robot outfitted with a colour depth camera and two ultra-wide band (UWB) sensors is used as the experimental platform for implementation. Experiments are carried out in a scenario where the robot follows a human user along a corridor while avoiding successive unknown objects and negotiating turns in order to assess. For patients with lower extremity impairment, it is especially crucial to support and oversee extended walking sessions in order to restore their independence during rehabilitation. Nevertheless, long-term manual help is sometimes impracticable due to a lack of caregivers and excessive nursing costs. To solve this, we suggest a walking-assistance robot that resembles a cane and is made to follow a human user, guaranteeing security and oversight during rehabilitation training. The robot adheres to a predetermined rule, keeping a particular relative posture to the user positioned a specified distance in front, 15–20 cm lateral to the healthy side, and aligned with the user's orientation inspired by clinical advice and user feedback. A quantitative approach to walking intention estimation is presented, using a Kalman filter and an inbuilt laser range finder to guarantee accurate human following. To improve the cane robot's human-following capabilities, a finite-time control technique is also used. Experimental findings confirm the efficacy of the suggested approach, showing that it can sustain acceptable human-following performance for a variety of users and walking styles.

Keywords: Human–robot collaboration, Autonomous mobile robot, Collision-free navigation, Cognitive robotic system (CRS), Soar cognitive architecture.

Introduction

With the development of human-robot collaboration, walking-assistance robots that resemble canes have been created to help people with lower limb problems who are still able to walk on their own. For safety and rehabilitation evaluation, patients in Category 4 or higher need standby help and supervision, according the functional ambulation categorization. However, traditional walking aids are insufficient for long-term daily supervision due to the lack of caretakers and the high expense of nursing care. This has led to the proposal of lightweight, mobile cane-type robots that will follow patients, offer physical assistance, and guarantee their safety while undergoing rehabilitation. Single-wheel robotic canes, fall detection and prevention systems, and omnibuses cane robots are examples of current versions. The robot should be positioned 30 to 45 cm in front of the healthy side and 15 to 20 cm laterally, in accordance with clinical recommendations. The three main components of human-following tasks are motion intention estimation, user detection, and robot movement control. Present-day approaches employ IMUs, laser range finders (LRFs), and vision sensors for detection, and filtering methods like the Kalman filter are used to estimate human motion. The stability and dynamic performance needed to maintain a constant relative position are frequently not satisfied by traditional control techniques like proportional control and PID, even if they aid in regulating movement. Ultra-wideband (UWB) sensors are used in this study's transmitter-receiver system to increase detection reliability. No matter the illumination or visibility circumstances, the robot's two UWB sensors receive signals from a transmitter the user carries, guaranteeing precise tracking. The efficiency of UWB signals through a variety of materials has been confirmed by research, making them a reliable option for practical uses. The suggested technique improves the accuracy of human following, offering a dependable and effective walking-assistance robot for rehabilitation.

Cognitive Robotic System:
The two main components of the Cognitive Robotic System (CRS) are figuring out the best course of action to follow a moving object while avoiding obstacles and figuring out the ideal speed for movement. Just as humans use sight and hearing to navigate, deciding whether to turn or move forward based on their environment, the CRS tracks the target and detects obstructions using UWB sensors and an RGB-D camera. To aid in decision-making, sensor data is transformed into symbolic information. The two primary parts of the CRS are the Reasoning Module, a cognitive agent built on the Soar cognitive architecture that analyses the robot's surroundings and makes navigational decisions, and the Speed Planning Module, which uses the Dynamic Window Approach (DWA) to translate these decisions into exact translational and rotational velocities for motor control. The robot can travel smoothly and effectively toward the destination while avoiding obstacles thanks to this combination, which allows it to dynamically adapt to its environment. The Dynamic Window Approach (DWA) is utilized by the Speed Planning Module to determine the ideal linear and rotational velocity values needed to power the robot's motors. Through constant modification of these velocity parameters, the CRS guarantees efficient, adaptable, and seamless navigation. This strategy enables the robot to react to changes in its surroundings in real time, guaranteeing that it will continue on a safe and steady path toward the moving target while successfully dodging obstacles. The integration of these components results in a strong and intelligent system that can follow people in real time in changing surroundings.

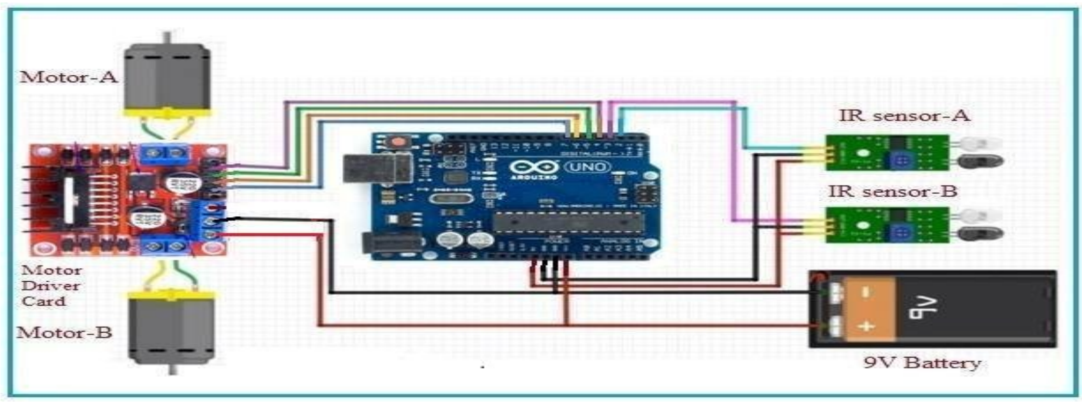

Figure 1. Circuit Diagram

Working of Components:

Infrared Sensor:

Figure 2. IR Sensor

An electronic gadget called an infrared (IR) sensor uses infrared radiation to either emit or detect particular aspects of its surroundings. These sensors are capable of both motion detection and heat emission measurement. Among the most basic and extensively utilized sensor modules, infrared sensor circuits are found in many electrical products. IR sensors use infrared radiation to identify impediments, much like human eyesight does. Passive infrared (PIR) sensors are those that solely pick up infrared light without giving it off. Every item emits heat radiation in the infrared spectrum, which is detectable by an infrared sensor but undetectable to the human eye. The sensor system is made up of two primary parts: an IR LED (light-emitting diode) for the emitter and an IR photodiode for the detector. The wavelength of infrared light that the LED emits is precisely what the photodiode is sensitive to. Effective detection of changes in infrared radiation is made possible by the photodiode's resistance and output voltage, which vary in proportion to the intensity of the IR light received.

Ultrasonic Sensor:
An electronic gadget called an ultrasonic sensor uses high-frequency sound waves to determine how far away an object is from it. It operates using the same echolocation mechanism as dolphins and bats to find their way around. The sensor waits for the echo to return after it bounces off an object after releasing a sound wave at a particular frequency. The sensor calculates the precise distance to the item using the formula Distance = (Speed of Sound × Time) / 2 by measuring the time interval between the sound wave's emission and reception. Because ultrasonic sensors can measure distances precisely without making physical touch, they are frequently utilized in applications including robotics, vehicle parking assistance, industrial automation, and obstacle detection systems. It is crucial to remember that ultrasonic sensors might not be able to detect certain objects. This limitation happens when sound waves are deflected away from an object instead of directly reflecting back to the sensor due to its form, surface texture, or placement. The precision of detection may be decreased, for instance, by objects with angled, soft, or

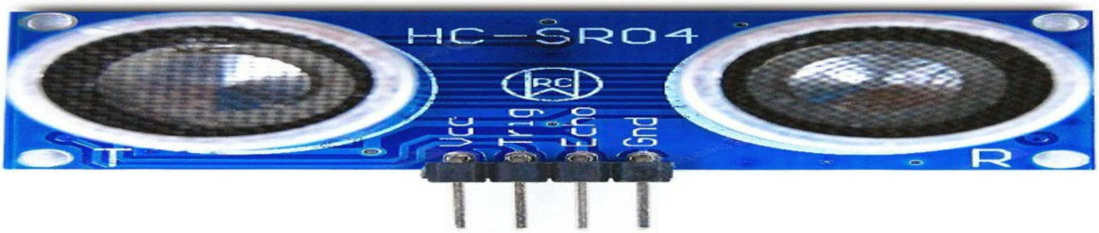

Figure 3. HC-SR04

uneven surfaces that absorb or scatter sound waves. In many real-world applications, ultrasonic sensors continue to be a dependable and effective non-contact distance measurement method in spite of these difficulties.

PIR Sensor:
A PIR (Passive Infrared) sensor uses variations in infrared radiation within its range of view to identify motion. Depending on the temperature and surface properties of the objects in its immediate vicinity, the sensor receives different amounts of infrared radiation. A human or other object moving in front of a wall or other background causes the temperature at that precise location in the sensor's field of view to change from room temperature to body temperature and back again. This shift in infrared radiation is picked up by the sensor, which transforms it into a change in output voltage that initiates motion detection. Furthermore, infrared radiation may be emitted in different patterns by objects with comparable temperatures but varying surface properties. Motion detection can also be achieved by shifting such objects in relation to the backdrop, which can also result in variations in the measured infrared levels. Because of this feature, PIR sensors are frequently employed in applications where detecting human presence is crucial, like security systems, automated lighting, and smart home automation.

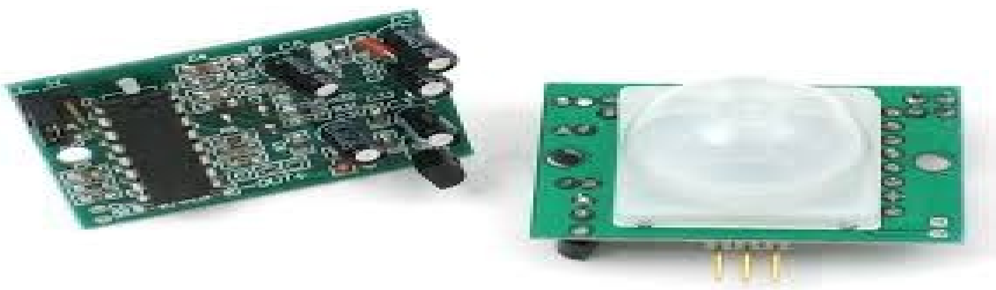

Figure 4. PIR Sensor

Arduino (Micro controller):
The Arduino microcontroller is open-source and convenient for users to program, erase, and reprogram. The Arduino platform was first released in 2005 with the goal of giving professionals, hobbyists, and students an accessible, adaptable, and user-friendly way to construct and prototype interactive electrical devices. Arduino is a well-liked option for robotics, automation, and Internet of Things applications because it employs sensors and actuators to allow users to build a variety of projects that engage with the environment. Simple microcontroller boards that function as a mini-computer at its core, processing inputs and managing outputs in accordance with user-defined instructions, make up Arduino. Arduino offers a streamlined development platform that makes it accessible even for novices, in contrast to conventional microcontrollers that call for intricate programming environments. Applications span from simple LED flashing projects to sophisticated robotics and home automation systems. The Arduino's ability to communicate with a variety of external modules and shields is one of its main advantages; it makes capabilities like wireless communication, internet connectivity, and motor control possible. The ability of Arduino to send and receive data over the internet over Wi-Fi, Bluetooth, and Ethernet shields makes it a popular option for Internet of Things (IoT) applications. It also facilitates smooth integration with other electronic components by supporting a variety of communication protocols, including SPI, UART, and I2C. In contrast to other microcontroller boards, Arduino was first limited to small-scale applications until becoming well-known in India in recent years. However, more engineers, developers, and students are utilizing

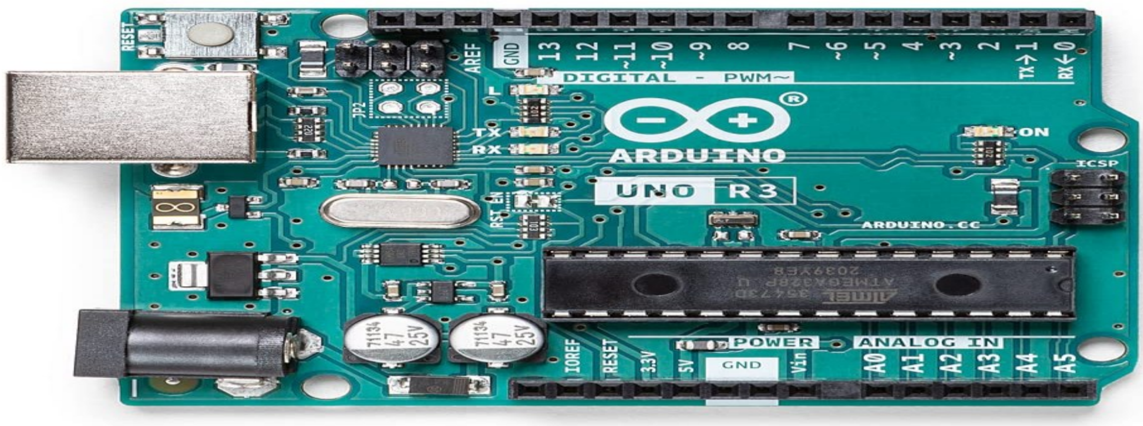

Figure 5. Arduino Uno (Micro-Controller)

Arduino for a variety of creative applications as a result of growing awareness of its potential. As a result of this broad popularity, Arduino communities, online resources, and open-source libraries have expanded, making it even simpler for novices to begin creating projects. A further noteworthy benefit of Arduino is its user-friendly programming interface. A basic USB connection allows users to write and upload code to the board. For both novice and expert programmers, the Arduino Integrated Development Environment (IDE) offers a graphical user interface that facilitates C and C++ development. Users may develop and test their projects more rapidly with the help of the IDE's built-in libraries and sample codes.

Need for Arduino:
Arduino is a popular microcontroller platform because of a number of important characteristics that set it apart from the competition. Arduino co-founder Massimo Banzi claims that the platform's vibrant user base, where users can exchange stories, troubleshoot difficulties, and work together to find solutions, is one of its biggest benefits. Innovation slows down if everything is sold, according to Banzi, underscoring the significance of an accessible and open community. Another important cause is the rise of Arduino, which was created specially to give professionals, students, and hobbyists an affordable and easy-to-use platform for making interactive devices with sensors and actuators. It is a great option for novices because of its simplicity of usage.

Lead Acid Battery:
A 12V 7Ah lead-acid battery is a type of rechargeable battery that is frequently used in many different applications, such as alarm systems, emergency lighting, UPS systems, solar power systems, toy cars, and small appliances. Its nominal voltage is 12V, and its capacity is 7Ah, meaning that it can supply 7 Amps for 1 hour or 1 Amp for 7 hours. It has a self-discharge rate of about 5-7% per month, and it can handle about 200-300 charge/discharge cycles before its capacity begins to degrade. When charging, it is advised to use a voltage of 14.4-14.7V and a current of 0.5-1.5A, with a charging time of about 4-6 hours for a full charge. To extend its lifespan, avoid deep discharging and overcharging, and store the battery in a cool, dry location.

Figure 6. Rechargeable Lead Acid Battery (12v-7Ah)

Arduino Code:

```
// Define RF inputs
#define SIGNAL_PIN1 2
#define SIGNAL_PIN2 3
#define SIGNAL_PIN3 4
#define SIGNAL_PIN4 5
// Define output pins
#define ACTUATOR1 6
#define ACTUATOR2 7
#define ACTUATOR3 8
#define ACTUATOR4 9
#define ACTUATOR5 10
const int SENSOR_TRIGGER_PIN = 11;  // Arduino pin connected to Ultrasonic Sensor's TRIG pin
const int SENSOR_ECHO_PIN = 12;  // Arduino pin connected to Ultrasonic Sensor's ECHO pin
const int CONTROL_PIN = A0;  // Arduino pin connected to Relay's pin
const int PROXIMITY_THRESHOLD = 50;  // centimeters
// Variables will change:
float pulseDuration, distanceValue;
void setup() {
  Serial.begin(9600);  // Initialize serial port
  pinMode(SENSOR_TRIGGER_PIN, OUTPUT);  // Set Arduino pin to output mode
  pinMode(SENSOR_ECHO_PIN, INPUT);  // Set Arduino pin to input mode
```

```
  pinMode(CONTROL_PIN, OUTPUT);  // Set Arduino pin to output mode
// Initialize Arduino inputs
  pinMode(SIGNAL_PIN1, INPUT);
  pinMode(SIGNAL_PIN2, INPUT);
  pinMode(SIGNAL_PIN3, INPUT);
  pinMode(SIGNAL_PIN4, INPUT);
  pinMode(ACTUATOR1, OUTPUT);
  digitalWrite(ACTUATOR1, LOW);  // Set output to LOW
  pinMode(ACTUATOR2, OUTPUT);
  digitalWrite(ACTUATOR2, LOW);  // Set output to LOW
  pinMode(ACTUATOR3, OUTPUT);
  digitalWrite(ACTUATOR3, LOW);  // Set output to LOW
  pinMode(ACTUATOR4, OUTPUT);
  digitalWrite(ACTUATOR4, LOW);  // Set output to LOW
}
void loop() {
  if ((digitalRead(SIGNAL_PIN1) == LOW) && (digitalRead(SIGNAL_PIN2) == LOW) &&
(digitalRead(SIGNAL_PIN3) == LOW) && (digitalRead(SIGNAL_PIN4) == LOW)) {
    digitalWrite(ACTUATOR1, LOW);
    digitalWrite(ACTUATOR2, LOW);
    digitalWrite(ACTUATOR3, LOW);
    digitalWrite(ACTUATOR4, LOW);
    digitalWrite(ACTUATOR5, HIGH);
  } else if ((digitalRead(SIGNAL_PIN1) == HIGH) && (digitalRead(SIGNAL_PIN2) == LOW) &&
(digitalRead(SIGNAL_PIN3) == LOW) && (digitalRead(SIGNAL_PIN4) == LOW)) {
    digitalWrite(ACTUATOR1, LOW);
    digitalWrite(ACTUATOR2, HIGH);
    digitalWrite(ACTUATOR3, LOW);
    digitalWrite(ACTUATOR4, HIGH);
    digitalWrite(ACTUATOR5, LOW);
  } else if ((digitalRead(SIGNAL_PIN1) == LOW) && (digitalRead(SIGNAL_PIN2) == HIGH) &&
(digitalRead(SIGNAL_PIN3) == LOW) && (digitalRead(SIGNAL_PIN4) == LOW)) {
    digitalWrite(ACTUATOR1, HIGH);
    digitalWrite(ACTUATOR2, LOW);
    digitalWrite(ACTUATOR3, HIGH);
    digitalWrite(ACTUATOR4, LOW);
    digitalWrite(ACTUATOR5, LOW);
  } else if ((digitalRead(SIGNAL_PIN1) == LOW) && (digitalRead(SIGNAL_PIN2) == HIGH) &&
(digitalRead(SIGNAL_PIN3) == HIGH) && (digitalRead(SIGNAL_PIN4) == LOW)) {
    digitalWrite(ACTUATOR1, LOW);
    digitalWrite(ACTUATOR2, LOW);
    digitalWrite(ACTUATOR3, LOW);
    digitalWrite(ACTUATOR4, LOW);
    digitalWrite(ACTUATOR5, LOW);
  } else if ((digitalRead(SIGNAL_PIN1) == LOW) && (digitalRead(SIGNAL_PIN2) == LOW) &&
(digitalRead(SIGNAL_PIN3) == LOW) && (digitalRead(SIGNAL_PIN4) == HIGH)) {
    digitalWrite(ACTUATOR1, HIGH);
    digitalWrite(ACTUATOR2, LOW);
    digitalWrite(ACTUATOR3, LOW);
    digitalWrite(ACTUATOR4, HIGH);
    digitalWrite(ACTUATOR5, LOW);
// Generate 10-microsecond pulse to SENSOR_TRIGGER_PIN
    digitalWrite(SENSOR_TRIGGER_PIN, HIGH);
    delayMicroseconds(10);
    digitalWrite(SENSOR_TRIGGER_PIN, LOW);
 // Measure duration of pulse from SENSOR_ECHO_PIN
    pulseDuration = pulseIn(SENSOR_ECHO_PIN, HIGH);
```

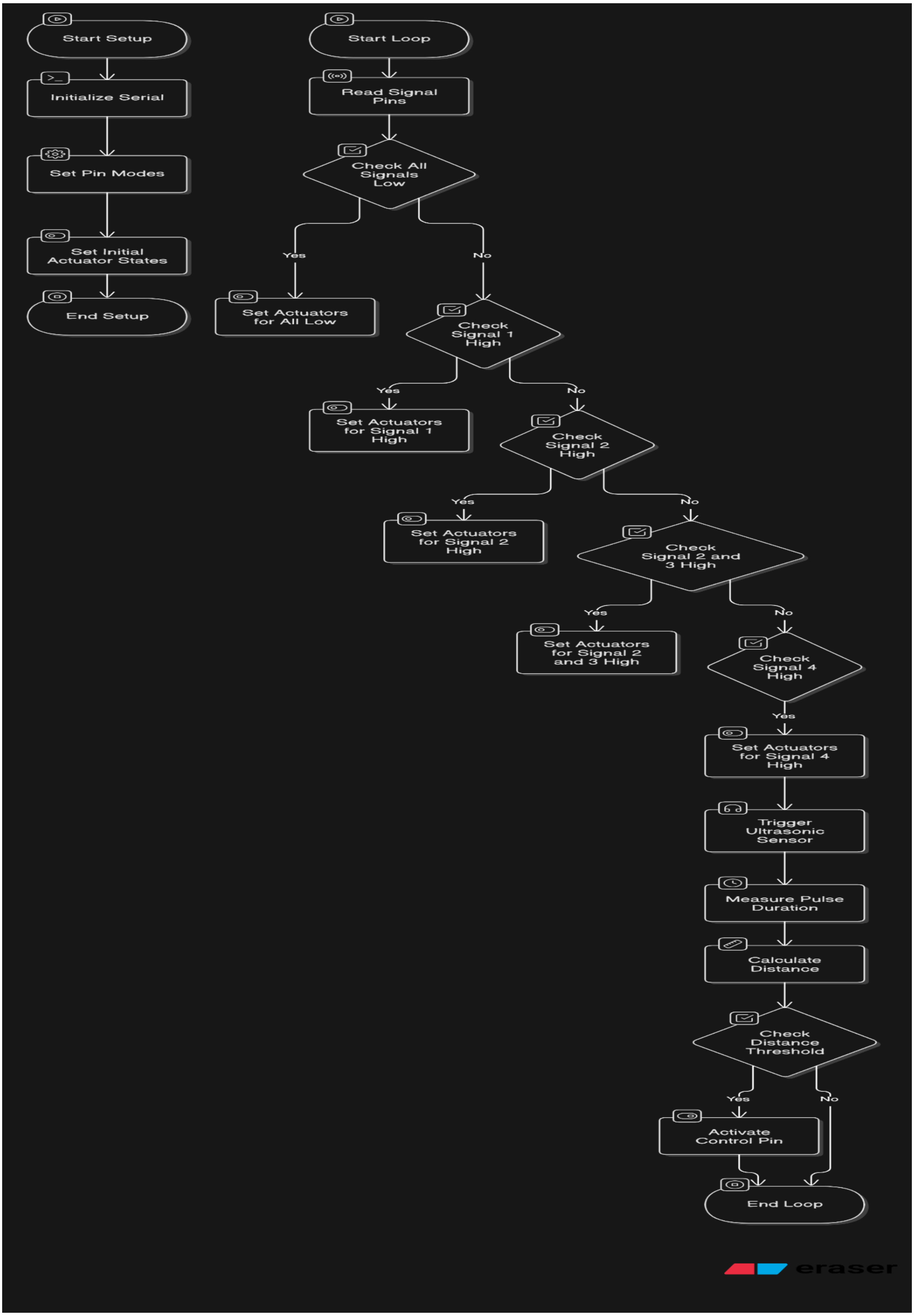

Figure 7. Flow Chart of Above Code

Results:

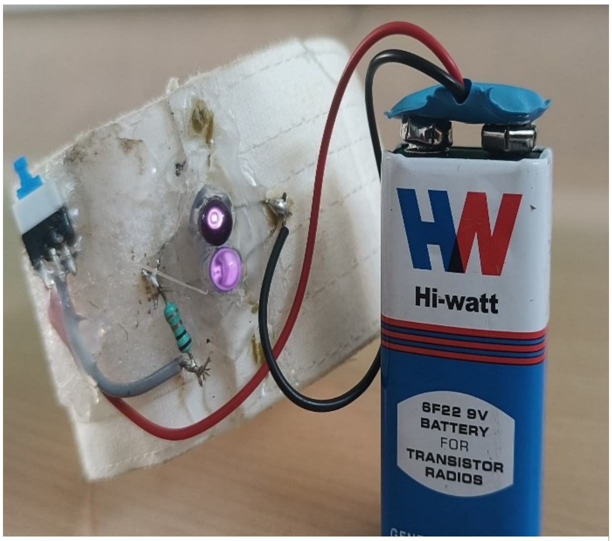

Figure 8. Personalized Hand Band

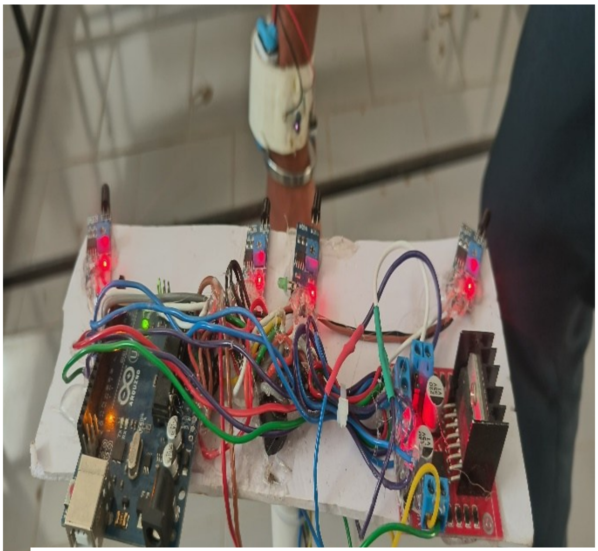

Figure 9. Wiring Harnessing

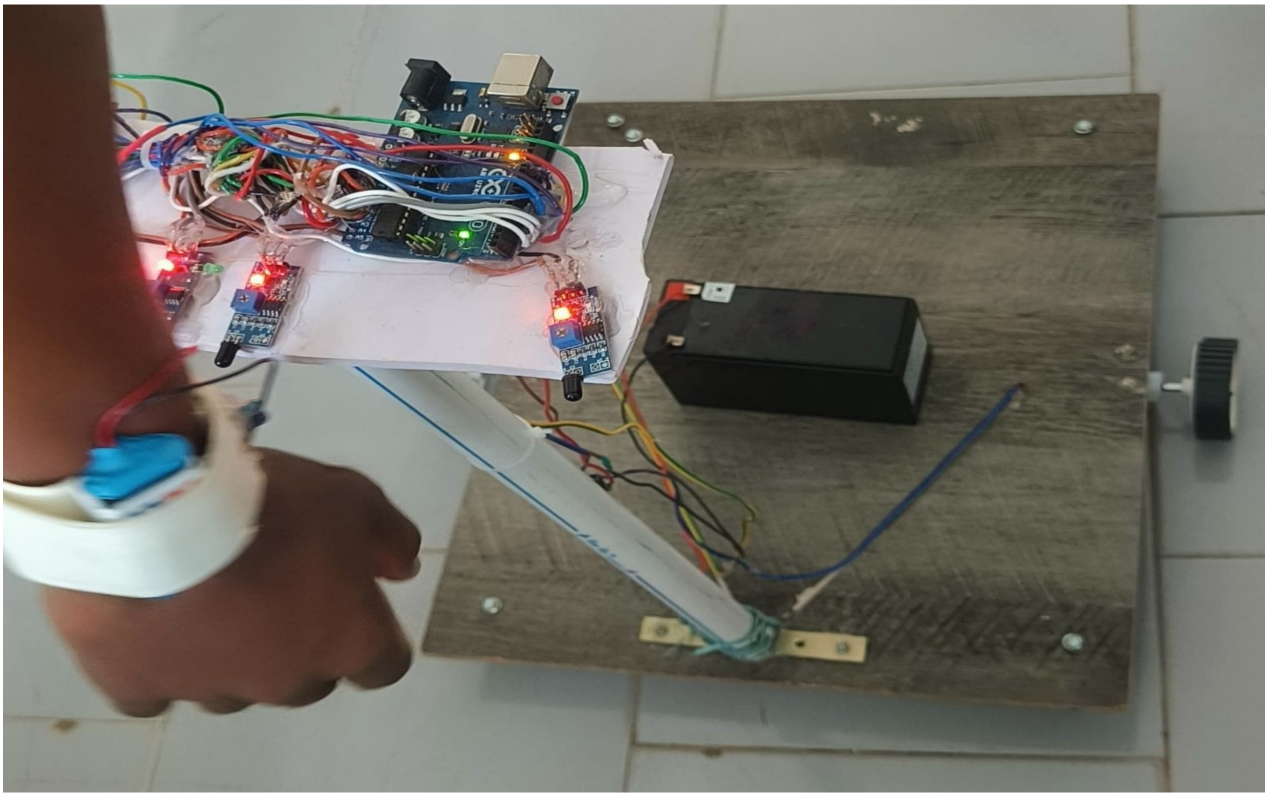

Figure 10. Top View of Human Following Robotic Model

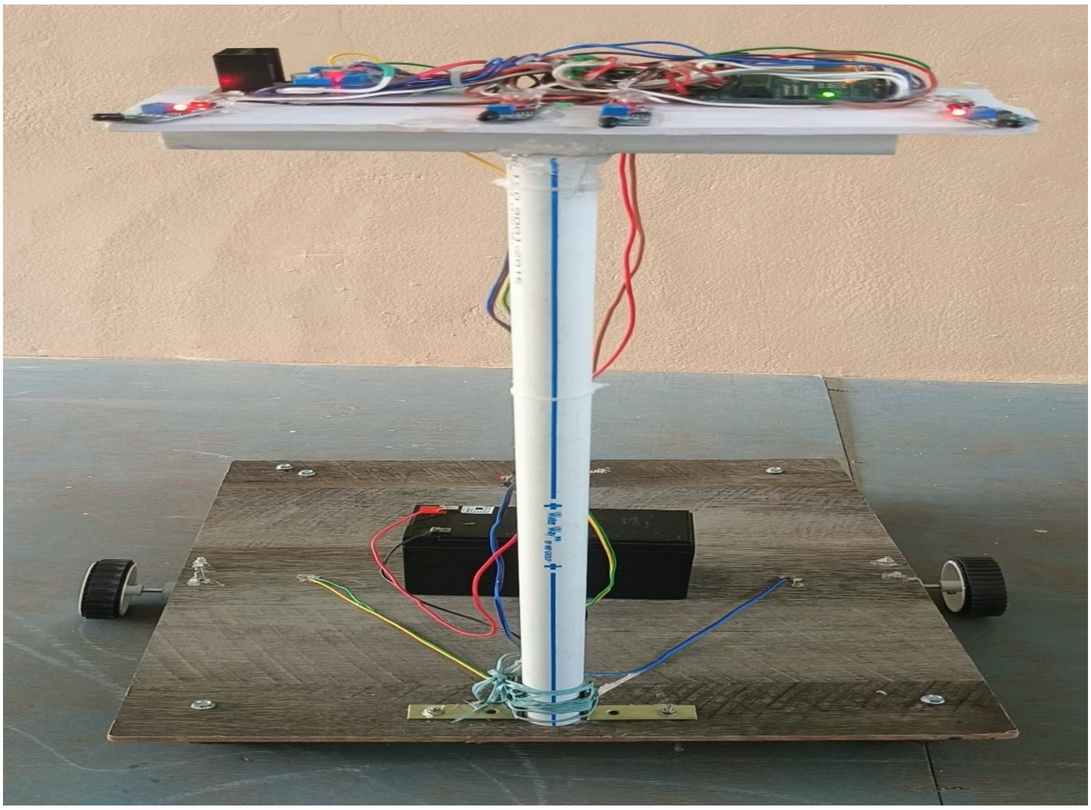

Figure 11. Front View of Human Following Robotic Model

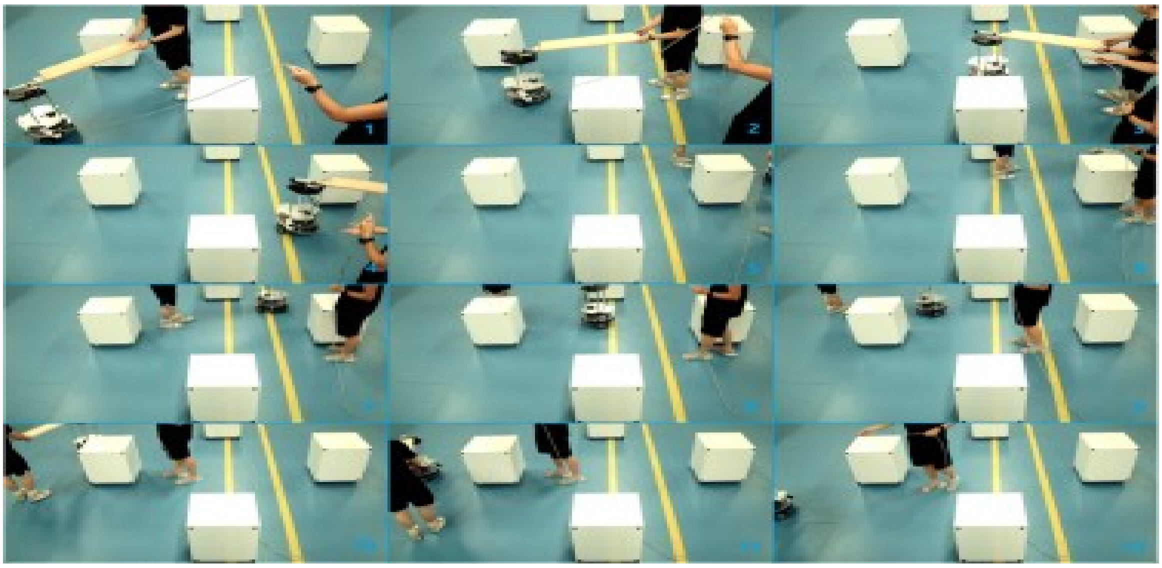

Figure 12. Real-time Checking with Obstacles

Conclusion

In order to guide a mobile robot toward a moving human target, this article introduces a Cognitive Robotic System (CRS) as a controller. The two main parts of the system are a modified Dynamic Window Approach (DWA) and a cognitive agent built on the Soar cognitive architecture. The cognitive agent is in charge of assessing the present state of the robot, making deft judgments to avoid obstacles, and advancing to the desired location. The ideal combination of translational and rotational velocities needed to regulate the robot's motors is then calculated by the modified DWA based on these choices. This CRS-based technique, in contrast to traditional methods for human-following vehicles, gives the robot human-like reasoning and decision-making abilities, enabling dynamic navigation while preserving human-robot collaboration. The ideal combination of translational and rotational velocities needed to regulate the robot's motors is then calculated by the modified DWA based on these choices. This CRS-based technique, in contrast to traditional methods for human-following vehicles, gives the robot human-like reasoning and decision-making abilities, enabling dynamic navigation while preserving human-robot collaboration.

A differential wheeled robot was used to test the effectiveness of the suggested system in three successive stages Tracking a moving target in a straight corridor, avoiding unknown obstacles while following the target, and regaining the target after it momentarily vanished at the intersection of two corridors. Although there are still certain restrictions, the results show that the CRS technique is feasible. A target walking slowly was used in the testing, and the system failed to take the target's orientation into consideration. Furthermore, the system's primary method of relative localization was Ultra-Wideband sensors, which might not be suitable in all settings. In order to overcome these constraints and enable use in more expansive and intricate settings where the robot must consistently follow a moving target, further research will focus on improving target detection, tracking speed, and adaptability.

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