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Department of Electronics & Communication Engineering

Project-based Learning (PBL): Microcontroller & Programming (EI243AI)

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Title: Adaptive Cruise Control

Introduction

Adaptive Cruise Control (ACC) is an intelligent system that automatically regulates vehicle speed to maintain a safe distance from obstacles, enhancing safety and reducing driver effort. This project implements a simplified ACC using an STM32 microcontroller, featuring real-time obstacle detection, speed monitoring of both the host and obstacle, and PWM-based motor control. The system enables a robotic vehicle to autonomously adapt its speed, supporting autonomous navigation and embedded systems education.

I. Problem Statement

In conventional cruise control systems, vehicles maintain a constant speed without adapting to changing traffic conditions, increasing the risk of collisions and reducing driving efficiency. There is a need for an intelligent system that can dynamically adjust the vehicle's speed, maintain a safe distance from other vehicles, and alert the driver to potential hazards to enhance safety and automation.

II. Objectives

1. Design and implement a system using an STM32 microcontroller that autonomously adjusts the vehicle's speed based on the distance to an obstacle, ensuring smooth operation and safe following behaviour in dynamic conditions.

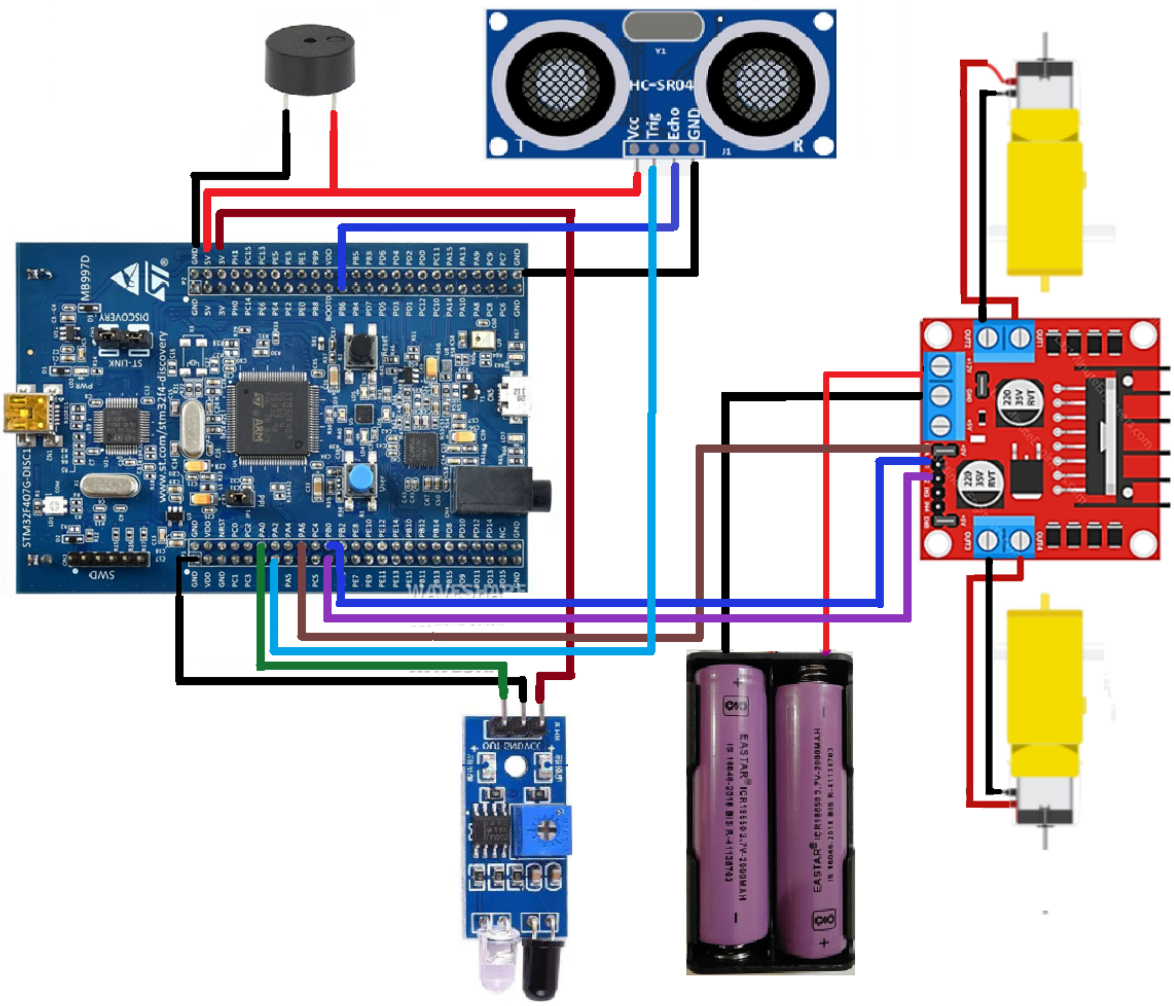
2. To successfully interface an ultrasonic sensor for obstacle detection, a motor driver for vehicle speed control, an IR sensor for host speed monitoring, and a buzzer for alert generation—all connected to the STM32 platform in a reliable and synchronized hardware setup.

3. To develop a real-time control algorithm that dynamically processes distance and speed data from sensors to compute PWM signals for motor control, enabling responsive speed adaptation and ensuring stable, closed-loop behaviour in real-world conditions.

4. To measure the host vehicle's speed using wheel rotation data and calculate obstacle speed through time-differential distance readings, that allow accurate tracking under various scenarios.

5. Implement threshold-based safety logic that activates a buzzer when the vehicle approaches dangerously close to an obstacle or experiences abnormal behaviour, ensuring driver notification and enabling potential override or future fail-safe integration.

III. Block Diagram/Circuit Diagram



IV. Components

•STM32F411E Discovery -Board-Central microcontroller for control, decision-making, and PWM output

•HC-SR04 Ultrasonic Sensor-Measures distance to the vehicle ahead

•L298N Motor Driver Module-Drives and controls the speed of two DC motors

•DC Motors with Wheels-Drives the chassis (host vehicle)

•Chassis Kit-Base frame for mounting motors and controller

•IR Sensor Module (Speed Sensor)-Measures the rotation speed of the host vehicle's wheel for speed calculation

•On-board LEDs (Green/Red)-Indicates safe or dangerous following distance

•Buzzer-Alerts when the following distance is too close (unsafe)

•3.7V Li-ion Batteries (×2)-Power supply for motors via L298N (~7.4V total)

•USB Connection / ST-LINK Programming and debugging interface for STM32

•Breadboard / Wires-For wiring additional components like IR sensor and buzzer

V. Tools/Technology used

- **Pulse Width Modulation (PWM)**-Controls motor speed based on distance to the front vehicle
- **Ultrasonic Ranging**-Time-of-flight principle used to measure distance from the front vehicle
- **Speed Calculation (IR)**-IR sensor detects wheel rotation; speed is computed using pulses over time
- **Real-time Embedded Control**-Continuously adjusts vehicle speed and indicates state using GPIOs and timers
- **Embedded C with HAL API**-Hardware control abstracted via STM32 HAL library for portability and ease of use

VI. Specifications

- Operating Voltage (MCU) 3.7V (STM32F411)
- Motor Supply Voltage ≈ 7.4V (powered by 2 × 3.7V Li-ion batteries)
- Buzzer Operating Voltage 5V
- IR Sensor Supply Voltage 3.3V
- Ultrasonic Sensor Range 2 cm – 400 cm
- Distance Threshold 10 cm (programmable)

Formulas:

Host Vehicle Speed = (Wheel Circumference × Pulses) / Time

Front Vehicle Speed Estimate=ΔDistance / ΔTime from consecutive ultrasonic readings

VII. Results & Discussions

1. Accurate Distance Measurement:
   The HC-SR04 ultrasonic sensor consistently measured the distance to the front object within ±1 cm accuracy up to 100 cm range.

2. Threshold Alert System Worked Reliably:
   When the distance dropped below 10 cm, the red on-board LED and buzzer were activated. For safe distances, the green LED remained on.

3. Dynamic Speed Adjustment:
   The speed of the host vehicle decreased smoothly as the front vehicle slowed down and increased again as safe distance was restored, using PWM control via L298N.

4. Host Speed Measurement via IR Sensor:
   The IR sensor effectively detected wheel rotations, allowing real-time calculation of host vehicle speed with acceptable precision (~5% error margin).

5. Stable Motor Performance:
   Powered by a 7.4V battery pack, the motors maintained consistent torque and speed across test conditions.

VIII. Outcomes

1. **Functional Adaptive Cruise Control Prototype Built:**
   Successfully implemented a basic ACC system using STM32F411E, capable of adjusting speed based on front vehicle distance.
2. **Maintained Safe Following Distance:**
   The system reliably maintained a minimum distance threshold (10 cm) using ultrasonic sensing and dynamic speed control.
3. **Real-Time Speed Adaptation Achieved:**
   Host vehicle speed was accurately varied in real-time through PWM adjustments, reflecting the distance and relative motion of the vehicle ahead.
4. **Effective Visual and Audio Alerts:**
   Red and green on-board LEDs and a buzzer provided immediate feedback on safe/unsafe distances.
5. **Host Vehicle Speed Measured Using IR Sensor:**
   Added speed estimation using an IR sensor and encoder logic, enhancing feedback on host motion.
6. **Successfully Integrated Multiple Sensors and Actuators:**
   Combined ultrasonic sensor, IR sensor, L298N motor driver, LEDs, and buzzer into a seamless embedded system.