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Development of an Embedded-Based Smart System for Safe Transport of Raw Materials to Tea Production Units

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Abstract

Tea plays a vital role in the Indian economy. In the year 2024, India was the second-largest tea producer in the world, contributing about 900 million kg and Assam being the largest contributor to the nation's total output. The quality of the final tea product and its economic value depend largely on the condition of freshly picked leaves when they arrive at the production unit. For safe and effective transportation, these raw tea leaves require a controlled environment. The required conditions for the leaves are a humidity level between 80–90% and an ambient temperature of less than 25°C.This paper presents the design and development of a low-cost embedded-based smart system to address reliable solution for preserving the freshness of tea leaves during transportation and ensuring vehicle safety.The system uses an AT89C52 microcontroller as its core and comprises two main subsystems. The first sub-system is an automated environmental control unit that uses a DHT11 sensor to measure temperature and humidity inside the transport vehicle and microcontroller activates a cooling apparatus and a humidifier to maintain the required environmental conditions. The second subsystem is an ultrasonic safety system using an HC-SR04 sensor to detect obstacles during vehicle reversing and provide warning through a buzzer and LCD display.

Keywords:*Embedded system, Tea transportation, microcontroller, ultrasonic sensor, temperature and humidity control*.

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1. Introduction

Tea plays a vital role in the agriculture and economy of India. India is the second-largest tea producer in the world and the state of Assam alone contributes a substantial share of the national production. The quality of tea is highly dependent on the condition of freshly plucked tea leaves before they undergo processing. Any deviation in environmental conditions such as temperature and humidity during transportation from tea gardens to tea production units can adversely affect the biochemical properties of tea leaves, leading to inferior quality tea.

Fresh tea leaves require a moderately cool and humid environment to retain their freshness. Studies indicate that the optimal humidity range lies between 80% and 90%, while the temperature should ideally remain below 25°C. Exposure to higher temperatures or lower humidity levels accelerates moisture loss, enzymatic reactions, and oxidation, which degrade leaf quality. Traditionally, transportation of tea leaves relies heavily on manual supervision and conventional vehicles without any environmental monitoring or control system. This lack of automation often results in inconsistent conditions and quality losses.

With advancements in embedded systems and microcontroller technology, it has become feasible to design intelligent, low-cost monitoring and control systems for agricultural applications. Embedded systems are dedicated computing systems designed to perform specific functions with high reliability and efficiency. The integration of sensors, microcontrollers and actuators enables real-time monitoring and automatic control of environmental parameters.

This work focuses on the development of an embedded-based smart system that ensures both environmental control and transportation safety. The proposed system monitors temperature and humidity using a DHT11 sensor and activates cooling or humidifying mechanisms whenever the measured values exceed predefined thresholds. In addition, an ultrasonic sensor (HC-SR04) is used to detect obstacles during vehicle reversing, thereby enhancing safety through buzzer alerts and visual indications on an LCD display. In case the vehicle is too close to the obstacle or about to collide, the system shuts off the engine.

The system is designed around the AT89C52 microcontroller, a widely used 8051-family microcontroller known for its simplicity, reliability and cost-effectiveness. By combining environmental monitoring with obstacle detection, the proposed solution addresses two critical challenges in tea leaf transportation: preservation of freshness and prevention of accidental damage.

2. A brief background of past works

Obstacle avoidance in mobile robots has been extensively researched using global and local navigation techniques, with ultrasonic sensors commonly employed for real-time obstacle detection. Earlier studies applied potential field methods and histogram-based mapping to enable safe navigation despite sensor inaccuracies. Real-time obstacle avoidance systems showed that continuous ultrasonic sampling improves detection reliability. With advancements in embedded platforms, Arduino-based robotic vehicles have integrated ultrasonic sensing with Bluetooth and Android applications. Ankit et al., (2016) have presented a low-cost robotic vehicle that combines ultrasonic obstacle detection with Android–Bluetooth control.Yalung et al., (2017)analyzed obstacle detection and material classification using an ultrasonic sensor, highlighting strong detection capability but poor classification performance. Using Ultrasonic-sensor-based obstacle detection Singh and Kapoor(2021) proposed a repeatable framework for generating obstacle data that models real-world obstacles. The results demonstrate reliable performance evaluation for future ultrasonic obstacle detection research.Further, monitoring temperature and humidity is critical in agriculture, pharmaceuticals, laboratories, and healthcare. Earlier systems relied on complex wired circuits, GSM alerts, and SMS notifications, which were often costly and unreliable. Limitations included missed alerts and lack of continuous monitoring. Arduino-based platforms with DHT11 sensors emerged as efficient alternatives.Srivastava et al.,(2018)present a simple and cost-effective Arduino–DHT11-based system for real-time temperature and humidity measurement. With the advancement of IoT technologies, low-cost DHT11 sensors integrated with microcontrollers have enabled real-time monitoring. NodeMCU ESP8266-based systems support wireless data transmission and smart phone visualization. Such systems are

now widely used Syahputra et al., (2023) have presented IoT-based monitoring system that provides real-time temperature and humidity data via Wi-Fi to an Android device.

3. System Overview and working

The proposed embedded system consists of two major functional subsystems: (i) obstacle detection for safe vehicle movement and (ii) temperature and humidity monitoring and control for maintaining leaf freshness. Both subsystems are coordinated by the 8051 microcontroller and share common output devices such as the LCD display.

3.1 Working Principle

At system startup, the microcontroller initializes all peripherals, including sensors and the LCD display. The DHT11 sensor provides digital temperature and humidity data at regular intervals. The ultrasonic sensor is triggered periodically to measure obstacle distance. Based on the sensor readings, the microcontroller executes conditional logic to control actuators and alert devices.

3.2 Hardware Components

3.2.1 8051 Development Board

AT89C52 microcontroller serves as core processing unit. It provides sufficient I/O ports, timers and memory resources for handling multiple sensors and output devices. The microcontroller operates with an 11.0592 MHz quartz crystal oscillator to ensure accurate timing.

8-bit CPU: Optimized for control applications

Flash Memory: 8KB of in-system programmable (ISP) Flash

RAM: 256 bytes of internal RAM

I/O Pins: 32 programmable I/O lines (organized into four 8-bit ports: P0, P1, P2, and P3)

Timers: Three 16-bit Timer/Counters

Interrupts: 8 interrupt sources

Clock Frequency: Typically operates from 0Hz up to 24MHz (requires an external crystal oscillator)

3.2.2 Ultrasonic Sensor (HC-SR04)

The HC-SR04 sensor operates on a 5 V supply and can measure distances from 2 cm to 400 cm with good accuracy. It uses a trigger and echo pin configuration to interface with the microcontroller.

Key Specifications of HC-SR04 ultrasonic sensor are as follows: -

Operating Frequency: 40 kHz

Effective Angle: < 15°

Ranging Distance: 2 cm – 400 cm

Resolution: 0.3 cm

3.2.3 DHT11 Sensor

The DHT11 sensor integrates a capacitive humidity sensor and an NTC thermistor, providing digital output for both parameters. Its low cost and ease of interfacing make it suitable for embedded applications.

Key Specifications of DTH 11 temperature humidity sensor are as follows: -

Humidity Range: 20% to 80% (5% accuracy)

Temperature Range: 0°C to 50°C (±2°C accuracy)

Sampling Rate: 1 Hz (One reading every second)

Operating Voltage: 3V to 5V

Max Current: 2.5mA (during conversion)

3.2.4 Relay Module, Buzzer, and LED

Relay modules are used to control high-power devices such as cooling and humidifying units. Buzzers and LEDs provide audio-visual alerts for obstacle detection and system status indication.

3.2.5 LCD Display (16×2)

A 16×2 LCD is used to display real-time sensor readings, system status and warning messages, enabling easy monitoring by the driver.

3.3 Obstacle Detection Subsystem

The obstacle detection subsystem is designed to assist the driver during vehicle reversing and parking. It comprises an ultrasonic sensor (HC-SR04), a buzzer, an LED indicator, and a 16×2 LCD display interfaced with the microcontroller. The ultrasonic sensor emits ultrasonic waves at a frequency of 40 kHz and measures the time taken for the echo to return after reflecting from an obstacle. The microcontroller calculates the distance based on the time delay and continuously displays it on the LCD.

When the measured distance falls below a predefined safety threshold (30 cm), the microcontroller triggers the buzzer and activates visual warnings. This alerts the driver and helps prevent collisions, thereby ensuring the physical safety of the vehicle and the transported tea leaves.

The obstacle detection system is designed to enhance vehicle safety during reversing and parking. As illustrated in Figure 1, the system integrates an ultrasonic distance measurement sensor with a microcontroller-based decision and alert mechanism.The schematic diagram of Figure 2 illustrates the complete hardware interconnections of the system, including sensor interfaces, power supply,

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oscillator circuit and output devices. Proper pull-up resistors and decoupling capacitors are used to ensure reliable operation.

The central processing unit of the subsystem is the AT89C52 microcontroller. The HC-SR04 ultrasonic sensor serves as the primary sensing device. It operates by emitting ultrasonic pulses at a frequency of 40 kHz through the transmitter. When these waves hit an obstacle, they are reflected back to the receiver. The sensor measures the time interval between transmission and receiving of the signal, which gives the distance between the vehicle and the obstacle.

The measured echo signal is transmitted to the microcontroller through the echo pin, while the trigger pin is controlled by the microcontroller to initiate measurement cycles. The microcontroller calculates the distance of the obstacle using internal timers. The calculated distance is displayed in real time on a 16×2 LCD display. When the measured distance falls below a threshold value of 30 cm, a buzzer produces an audible alarm and an LED indicator provides a visual warning to alert the driver. In case the vehicle is too close to the obstacle or about to collide, the system shuts off the engine by using simple relation between speed of sound with time .This design ensures obstacle detection with simple interfacing and reliable operation, making it suitable for transport vehicles carrying fresh tea leaves.

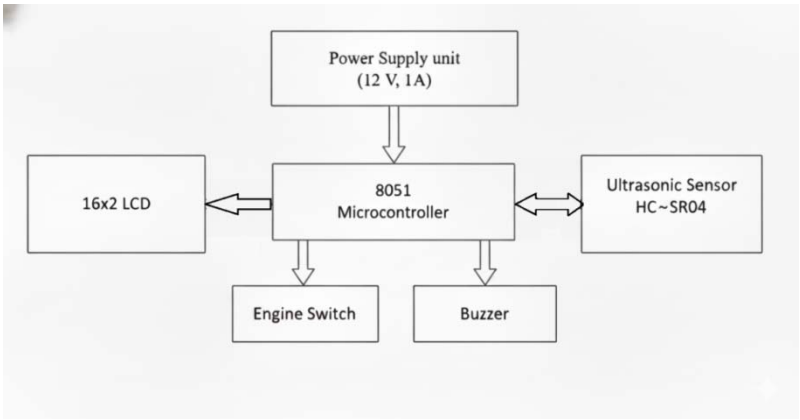


Figure 1- A simplified block Diagram of Obstacle Detection Subsystem

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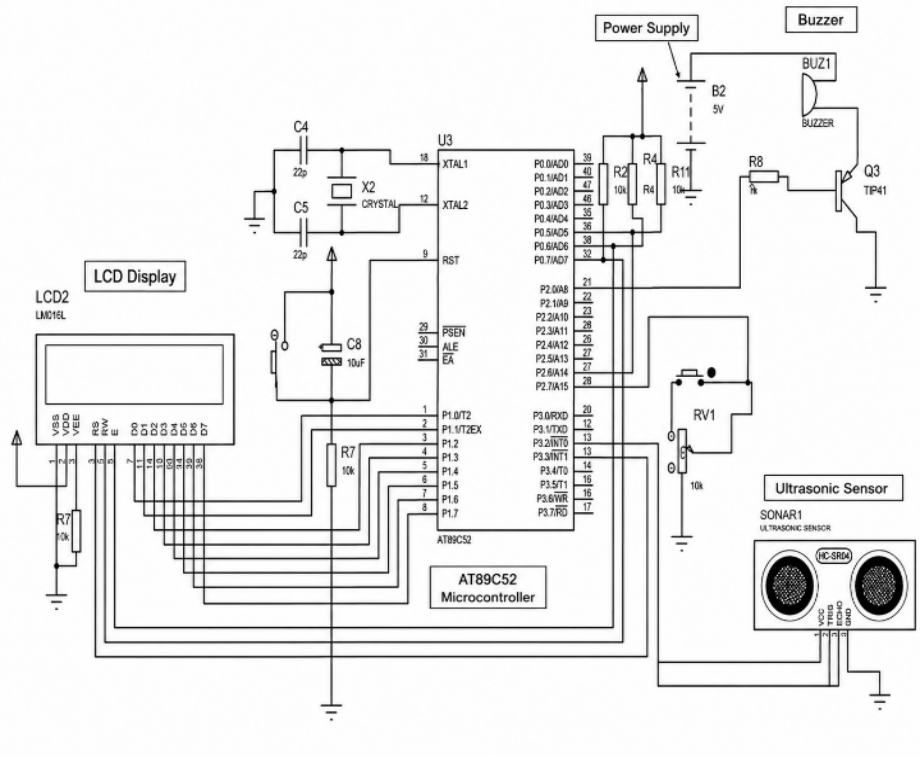


Figure 2: Schematic diagram of Obstacle Detection System

3.4 Temperature and Humidity Monitoring Subsystem

The environmental monitoring subsystem consists of a DHT11 temperature and humidity sensor, relay-controlled actuators (cooling, humidifying, and dehumidifying units), and an LCD display (block diagram of Figure 3).The DHT11 sensor continuously measures the ambient temperature and relative humidity inside the vehicle. These values are processed by the microcontroller and compared with predefined threshold values.If the temperature exceeds 25°C, the microcontroller activates the cooling mechanism through a relay module. Similarly, if the humidity falls below 80%, the humidifier is activated, and if the humidity rises above 90%, the dehumidifier is activated. This closed-loop control ensures that tea leaves are transported under ideal environmental conditions.The temperature

and humidity monitoring subsystem is responsible for maintaining the optimal environmental conditions required for preserving the freshness of freshly plucked tea leaves during transportation. The block diagram shown in Figure 3 and the detailed description given in Figure 4 illustrate the integration of environmental sensors, control logic, and actuators.Here, the DHT11 sensor data pin is connected to a digital I/O port with a pull-up resistor. Relay modules are driven through transistor interfaces to control external actuators safely.The DHT11 sensor contains a capacitive humidity sensing element and a thermistor for temperature measurement, providing digital output signals directly to the microcontroller. The measured environmental parameters are periodically transmitted to the AT89C52 microcontroller, which processes the data and compares it with threshold values. According to agronomic requirements, the recommended environmental conditions include a temperature below 25°C and a relative humidity range between 80% and 90%.

All environmental readings and system status messages are continuously displayed on the 16×2 LCD display, enabling the operator or driver to monitor the conditions inside the vehicle. The relay modules act as switching interfaces between the low-power microcontroller signals and the higher-power cooling and humidifying devices.

Through this closed-loop monitoring and control mechanism, the subsystem ensures that environmental conditions remain within the required range, thereby preserving the quality of tea leaves during transportation.

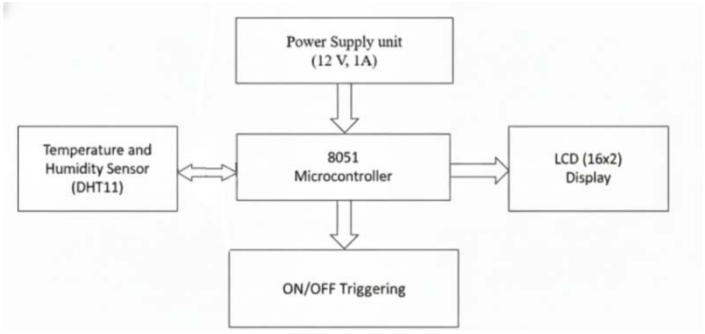


Figure 3: Block Diagram of Temperature and Humidity Monitoring Subsystem

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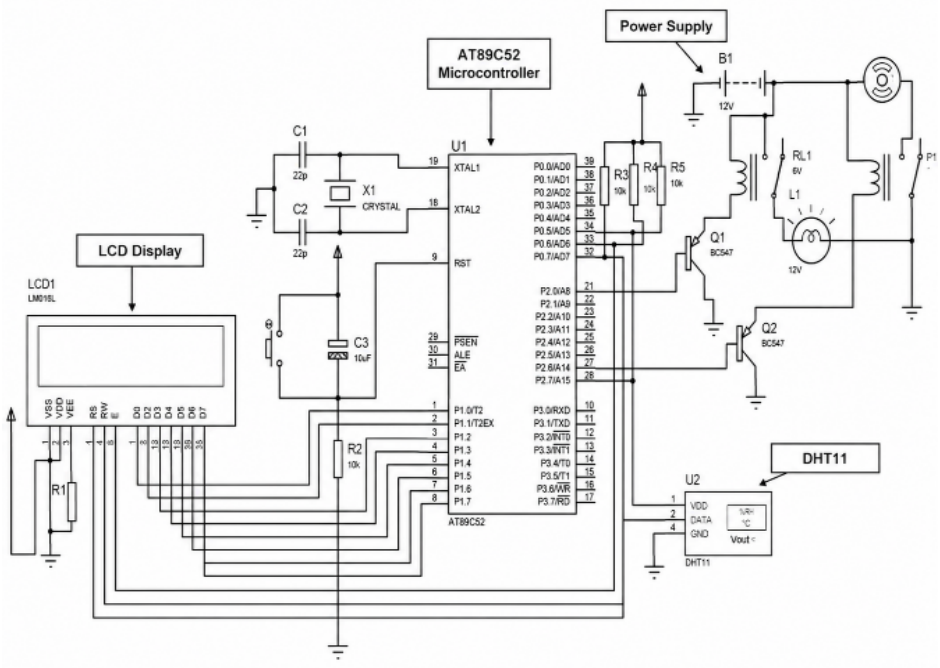


Figure 4 : The detailed components and devices of the Temperature and Humidity monitoring module.

4. Software Tools

The embedded software is developed using Keil µVision IDE which supports programming in Embedded C and debugging. Proteus simulation software is used to verify the circuit design and logic before hardware implementation.

5. Flowchart description

The system follows a continuous, real-time logic loop which is divided into two parallel functional paths after the initial startup.Upon startup, the AT89C52 microcontroller initializes all connected peripherals i.e. 16x2 LCD, HC-SR04 ultrasonic sensor and DHT11 sensor. It specifically sets the initial states for the buzzer, thermostat and humidistat to zero (OFF).

For environment monitoring, the system reads digital temperature and humidity data from the DHT11 and displays these values on the LCD, as displayed in the Flowchart of Figure 5a. If the temperature exceeds 25°C, the microcontroller triggers the thermostat (cooling unit). It remains ON

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until the temperature drops below the 25°C threshold. The system checks if humidity is within the 80-90% target range. If humidity exceeds 90%, the humidistat (dehumidifier) is activated. If humidity falls below 80%, the humidifier is activated.

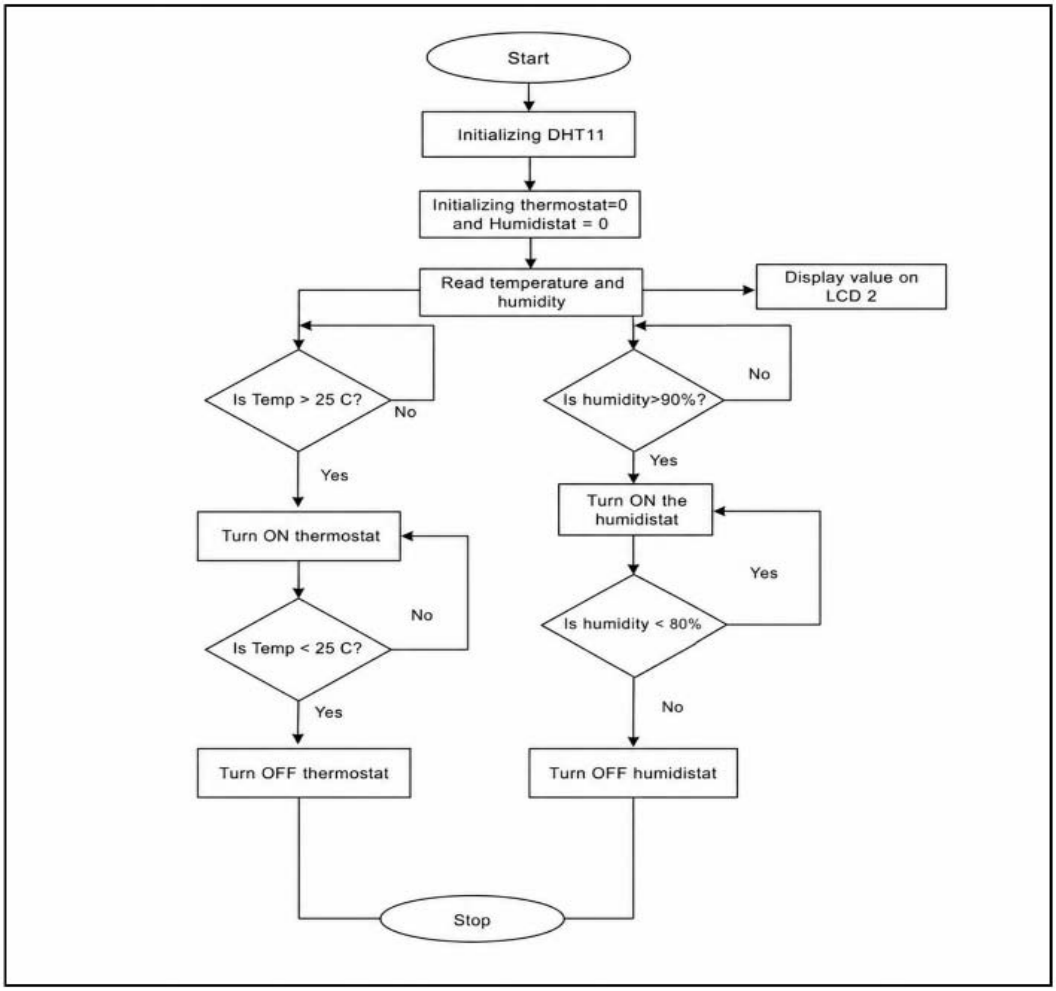


Figure 5a : Flow chart related to environment monitoring

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For Obstacle Detection, the system triggers the HC-SR04 to measure the distance to any rear obstacles in centimeters. If the detected distance is less than 30 cm, the microcontroller executes three immediate actions: it turns on the audible buzzer alarm, displays the warning/distance on the LCD, and triggers a command to turn OFF the vehicle engine (reverse gear) to prevent collision, (Flow chart in Figure 5b).

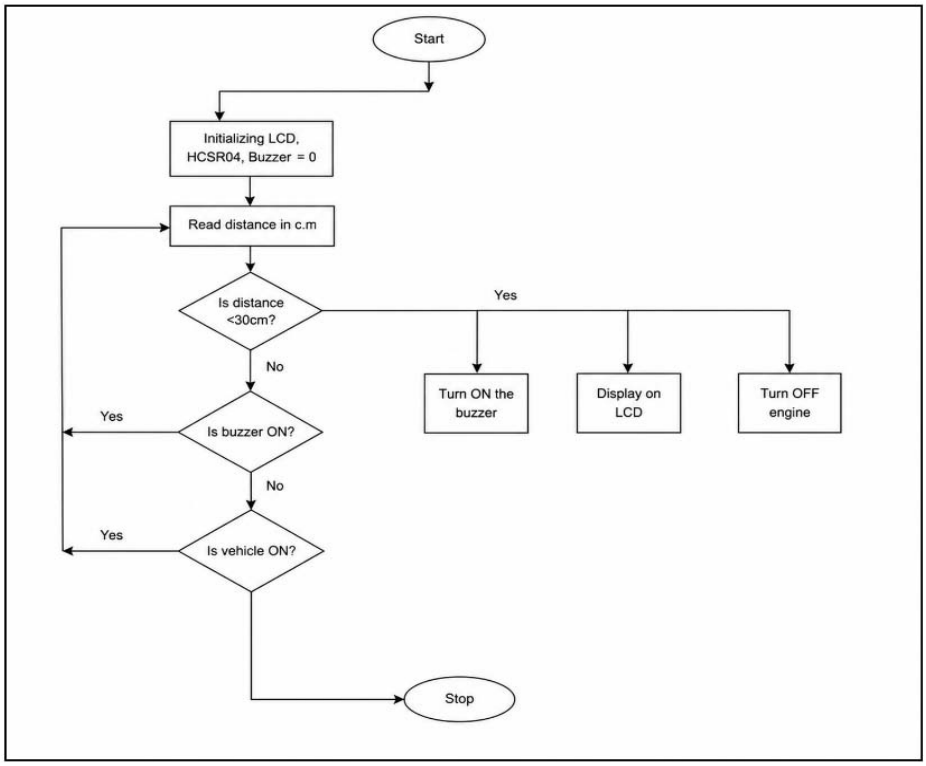


Figure 5b : Flow chart in obstacle detection

After these conditional checks, the program returns to the sensing phase, repeating the cycle to ensure constant monitoring during transport.

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6. Program : The detailed program is described in the Appendix

The image of the final assembled system is displayed in Figure 6

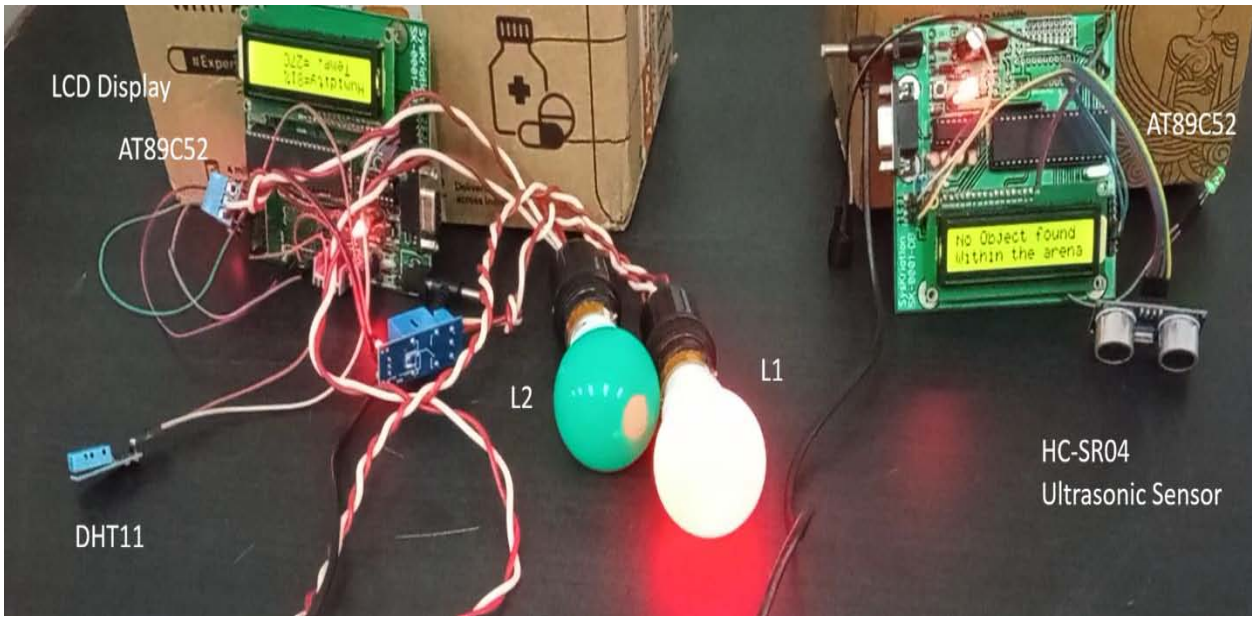


Figure 6 :The embedded system is displayed in photograph where temperature exceeds 25℃ i.e. 27℃ so the bulb connected with DHT11 turns on indicating activation of cooling fan

7. Applications and Advantage

- Safe transportation of freshly plucked tea leaves
- Environmental monitoring in agricultural transport vehicles
- Obstacle detection and parking assistance systems.
- Low-cost and simple design
- Real-time monitoring and control

- Easy installation and maintenance
- Improved quality preservation of tea leaves

8. Limitations and Conclusions

- Limited accuracy of DHT11 sensor
- Restricted range of ultrasonic sensor
- Lack of wireless communication and data logging

This paper presented an embedded system designed to ensure safe transportation of fresh tea leaves by maintaining optimal environmental conditions and enhancing vehicle safety. The system successfully integrates temperature, humidity and obstacle detection using low-cost sensors and 8051 microcontroller. Experimental results demonstrate that the proposed system effectively preserves leaf freshness and reduces transportation risks. Due to its simplicity and affordability, the system is well-suited for practical deployment in tea-producing regions.Future enhancements may include integration of wireless communication modules for remote monitoring, GPS-based vehicle tracking, higher-accuracy sensors and data logging for quality analysis. The system can also be extended to other agricultural commodities requiring controlled transportation environments.

.

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Datasheet of DHT11 Temperature and Humidity Sensor.

Datasheet of HC-SR04 Ultrasonic Sensor.

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Appendix

The Program

Referred I the appendix

```
#include <reg51.h>
#include <intrins.h>
#define dataport P1
sfr16 DPTR=0x82;
sbitrs=P0^5;
sbitrw=P0^6;
sbit e=P0^7;
sbit trig=P3^3;
sbit echo=P3^2;
sbit alarm=P2^0;
sbitengine_switch=P2^1;
unsigned int range=0;
int x;
////////////////////////////////////Delay program
void delay(unsigned int msec)
{
  int i,j;
  for(i=0;i<msec;i++)
            {
  for(j=0;j<1275;j++);
            }
```

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```
}
//////////////////////////////////// Function for creating delay of 10 Microseconds
void delay10us()
{
_nop_(); _nop_(); _nop_(); _nop_(); _nop_();
_nop_(); _nop_(); _nop_(); _nop_(); _nop_();
}
////////////////////////////////////Function to interface ultrasonic Sensor
unsigned char ultrasonic()
{
        unsigned char dataD;
        trig=1;                         //These three line is to generate ultrasonic sound of 40 Khz
        delay10us();
        trig=0;

        while(INT0==0);         /////// Wait untill INT0 pin (echo pin) high
        while(INT0==1);                 /////// Wait untill INT0 pin (echo pin) low
        DPH=TH0;                                        ////////Store TH0 value to DPH
        DPL=TL0;                                        ////////Store TL0 value to DPL
        TH0=TL0=0xff;

        dataD=DPTR/59;                          ////////// 59 from calculation
        return dataD;
}
```

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```
//////////////////////////// Function to send command to LCD
void lcd_cmd(unsigned char item)
{
dataport = item;
rs=0;
rw=0;
  e=1;
delay(1);
  e=0;
}
//////////////////////////////// Function to send data to LCD

void lcd_data(unsigned char item)
{
        dataport = item;
rs=1;
rw=0;
  e=1;
delay(1);
  e=0;
}
//////////////////////////////// Function to send more than one character/data
void message(unsigned char *s)
```

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```
{
        while(*s)
                lcd_data(*s++);
}
////////////////////////////////Function to ininitialize LCD

void lcdinit()
{
        lcd_cmd(0x38); //8 bit mode
        lcd_cmd(0x06); //display from left to right
        lcd_cmd(0x0C);          //display ON, cursor hide
        lcd_cmd(0x01);  //clear LCD
}

//////////////////////////////////////Main program
void main()
{
        alarm=0;
        engine_switch=0;
lcdinit();
        lcd_cmd(0x80);
        message("  Initialising  ");
        lcd_cmd(0xc0);
        message(" Parking System ");
```

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```
        delay(700);
////////////////////////////////////Code for ultrasonic sensor
        trig=0;
        TMOD=0x09;          //Timer 0 ; Mode 1 i.e16 bit Timer
        TH0=TL0=0;          //Load the TH0 and TL0 with 0
        TR0=1;                      // Start the Timer 0
        echo=1;
while(1)
 {
        lcdinit();
lcd_cmd(0x80);
message("  Obstacle at=  ");
 range=ultrasonic();
        lcd_cmd(0xc4);
        lcd_data((range/100)+48);
        lcd_data(((range%100)/10)+48);
        lcd_data(((range%100)%10)+48);
        lcd_cmd(0xc7);
        message("cm");delay(100);
                if(range<30)
                {
                        alarm=1;
                        engine_switch=0;
                }
```

```
                else
                {
                        alarm=0;
                        engine_switch=1;
                }
  }
}

#include <reg51.h>
#define dataport P1

sbitrs=P0^5;
sbitrw=P0^6;
sbit e=P0^7;

sbit DHT11=P2^7;

int I_RH, D_RH, I_Temp, D_Temp, CheckSum;

int x;
unsigned char cmd;
int i,j;

//////////////////Delay Program
```

```
void delay (unsigned int msec)
{
        for (i=0;i<msec;i++)
        for (j=0;j<1000;j++);
}

void delay20ms()
{
        TMOD = 0x01;
        TH0 = 0xB8;
        TL0 = 0x0C;
        TR0 = 1;
        while (TF0 == 0);
        TR0 = 0;
        TF0 = 0;
}

//////////////30 Microsecond delay function
void delay30us()
{
        TMOD = 0x01;
        TH0 = 0xFF;
        TL0 = 0xE4;
        TR0 = 1;
```

```
        while (TF0 == 0);
        TR0 = 0;
        TF0 = 0;
}
//////////////Function to send command to LCD
void lcd_cmd(unsigned char item)
{
        dataport = item;
        rs=0;
        rw=0;
        e=1;
        delay (1);
        e=0;
}
//////////Function to send data to LCD

void lcd_data(unsigned char item)
{
        dataport = item;
        rs=1;
        rw=0;
        e=1;
        delay (1);
        e=0;
```

```
}
///////Function to send more than one character
void message (unsigned char *s)
{
        while (*s)
                lcd_data(*s++);
}
//////LCD initialising command
void lcdinit()
{
        lcd_cmd(0x38);
        lcd_cmd(0x06);
        lcd_cmd(0x0C);
        lcd_cmd(0x01);
}
/////Microcontroller send request
void Request()
{
        DHT11 = 0;
        delay20ms();
        DHT11 = 1;
}
/////Function for receive response from DHT11
void Response()
```

```
{
        while(DHT11==1);
        while(DHT11==0);
        while(DHT11==1);
}
////Function to receive data (0,1) from DHT11
int Receive_data()
{
        int q,c=0;
        for (q=0; q<8; q++)
        {
                while (DHT11==0);
                delay30us();
                if(DHT11 == 1)
                        c = (c<<1)|(0x01);
                else
                        c = (c<<1);
                while (DHT11==1);
        }
        return c;
}

//////Main function
void main()
```

```
{
        unsigned int a, b, c, d;
        lcdinit();
        lcd_cmd(0x01);
        lcd_cmd(0x80);
        message("Initialising");
        lcd_cmd(0x8c);
        lcd_data('.');
        delay(50);
        lcd_cmd(0x8d);
        lcd_data('.');
        delay(50);
        lcd_cmd(0x8e);
        lcd_data('.');
        delay(50);
        lcd_cmd(0x8f);
        lcd_data('.');
        delay(50);
        lcd_cmd(0x01);
        while(1)
        {
                lcdinit();
                Request();
                Response();
```

```
I_RH=Receive_data();
D_RH=Receive_data();
I_Temp=Receive_data();
D_Temp=Receive_data();
CheckSum=Receive_data();

if ((I_RH + D_RH + I_Temp + D_Temp) !=CheckSum)
{
        lcd_cmd(0x80);
        message (" Invalid Data ");
        lcd_cmd(0x01);
}

else
{
        lcd_cmd(0x01);
        /////////To display humidity valur
        lcd_cmd(0x80);
        message("Humidity=");
        a=(I_RH/10)+48;
        b=(I_RH%10)+48;
        lcd_cmd(0x89);
        lcd_data(a);
        lcd_cmd(0x8A);
```

```
                    lcd_data(b);
                    lcd_cmd(0x8B);
                    lcd_data('%');
                    //////To display temp.value
                    lcd_cmd(0xc0);
                    message(" Temp. =");
                    c=(I_Temp/10)+48;
                    d=(I_Temp%10)+48;
                    lcd_cmd(0xc9);
                    lcd_data(c);
                    lcd_cmd(0xcA);
                    lcd_data(d);
                    lcd_cmd(0xcB);
                    lcd_data('C');
                    delay(1000);
                }
            }
        }
```