Design and Implementation of Miniature Learning Vacuum Robots Using Ultrasonic Sensing and PIC16F877A Microcontroller

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***Abstract* - The study explores the design and implementation of a cost-effective miniature learning vacuum robot utilizing the PIC16F877A microcontroller and ultrasonic sensing. The PIC16F877A's affordability and features make it ideal for this application. The circuitry includes the HC-SR0 sensor and L293D motor driver. Software-wise, MikroC programming enables autonomous navigation and obstacle avoidance. The project's significance lies in affordability, innovation, and practicality. By prioritizing affordability, it makes home automation accessible. Technological innovation enhances functionality, while practical implementation ensures real-world usability.**

Index Terms - Microcontroller, Automated Robotics, Ultrasonic Sensor, Autonomous Cleaning Devices, Obstacle Detection

I. Introduction

In recent years, the field of home automation has witnessed great advancements with the introduction of autonomous cleaning devices. Among these, vacuum robots have garnered considerable attention for their ability to automate the task of floor cleaning, thereby offering enhanced convenience and efficiency. Initially, these devices were simplistic and manually operated; however, advancements in technology have enabled their evolution into fully autonomous systems equipped with sophisticated navigation capabilities through the incorporation of sensors and advanced algorithms. Despite technological progress, this evolution has concurrently led to an increase in the cost of vacuum robots, thereby creating a notable gap in the market for individuals seeking effective yet affordable solutions.

Figure 1. A Common Roomba [1]

Addressing this gap, the current research focuses on the design and implementation of a cost-effective miniature learning vacuum robot that leverages the PIC16F877A microcontroller in conjunction with ultrasonic sensing. The PIC16F877A microcontroller is selected for its affordability, widespread availability, and comprehensive feature set, which includes Input/Output (IO) ports, analog-to-digital converters, and Pulse Width Modulation (PWM) outputs. These features render it an ideal candidate for the development of a budget-friendly autonomous cleaning device. The primary objective of this research is to harness the capabilities of the PIC16F877A microcontroller, alongside ultrasonic sensors, to enable the vacuum robot to navigate independently, avoid obstacles, and maintain cleanliness, all while remaining cost-efficient.

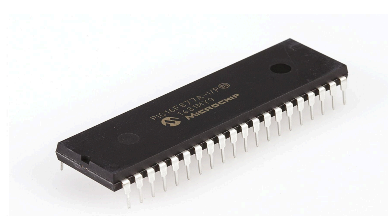

Figure 2. The Microcontroller Used for the Project [2]

This study aims to contribute to the field by presenting a viable alternative that prioritizes both affordability and functionality. By employing the PIC16F877A microcontroller and programming it in C language using MikroC, the research endeavors to implement complex functionalities essential for autonomous navigation and obstacle detection. Such functionalities include motor operations, ultrasonic sensor-based obstacle detection and avoidance, and efficient battery management. The methodology adopted in this research involves the integration of the aforementioned hardware components into a compact design, with the microcontroller programmed to manage the robot's operations, including navigation algorithms, obstacle detection, and cleaning routines.

II. Design and Application

The integration of ultrasonic sensors with the PIC16F877A microcontroller would be the foundation of this paper and the existence of Aswinth Raj's work would serve as the basis on this project. Raj's project is an Obstacle Avoiding Robot that also uses PIC16F877A which offers a relevant template for the group to enhance and add a significant function [3].

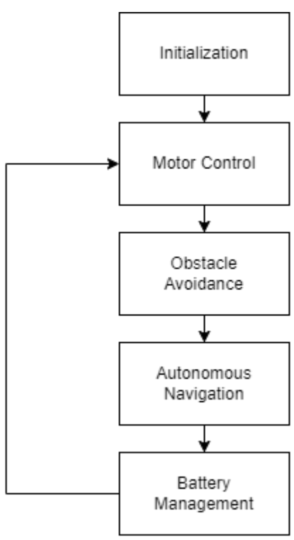

Figure 3. Program Flowchart

The flowchart above illustrates the development of the vacuum robot using the PIC16F877A microcontroller. The hardware components, such as the microcontroller, motors, ultrasonic sensors, and battery, are assembled for the initialization. The microcontroller is initialized, and its Input/Output (IO) ports are set up for communication with other components. In the motor control, the robot continuously analyzes data from its ultrasonic sensor to detect obstructions in its path. If no obstacles are found, the robot will go forward.

When an obstacle is detected, the robot uses an ultrasonic sensor to determine the direction of the obstacle. It then turns away from the obstruction to prevent a collision. After successfully avoiding the obstacle, the robot resumes onward motion. The robot's autonomous navigation requires continual sensor data processing. It continues to read data from the ultrasonic sensor. Based on obstacle detection, the robot modifies its movement. A simple path-following algorithm is used (e.g., proceed until an obstruction is reached, then turn). The robot monitors its battery voltage to ensure the robot's lifespan and avoid unexpected shutdowns. If the battery voltage becomes dangerously low, the robot ceases operations to avoid damage. The entire process is repeated from step 2, allowing the robot to travel, avoid obstacles, and clean the floor indefinitely.

Circuit Related

Figure 4. HC-SR0 Component [4]

As shown in the schematic diagram, the core of the machine's navigation system will depend on the ultrasonic sensor HC-SR0, which is a low-cost solution for no contact distance measurement function but due to the unavailability of the sensor component in KiCad, the group replaced the sensor into a potentiometer. Alongside it will be interfaced with the PIC16F877A microcontroller which will be the heart of the circuit. The sensor's echo pin is connected to the RB6 pin, while the trigger pin is connected to the RB7 pin. This function allows the vacuum robot to avoid obstacles and go in a different direction when the sensor detects an object nearby. This is achieved by driving the motor connected to OUT1 and OUT2 in a counterclockwise direction, and simultaneously spinning the motor connected to OUT3 and OUT clockwise, with a slight speed increase to allow for the different turning radii between the two wheels. The LCD communicates the vacuum's operation which is either "turning" or "moving forward" through the RB0 to RB pins for feedback.

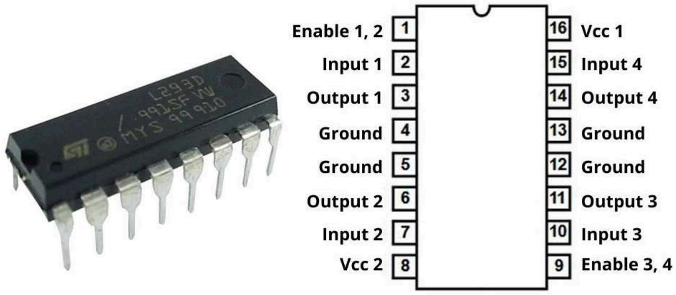

Figure 5. IC-L293D Component [5]

The motor driver IC L293D is connected to the outputs of the microcontroller, which regulates the motor speeds for maneuvering the robot. The LED has been designated as the vacuum-on indicator and it is connected to an RD7 pin, which is set into a high state or would turn on the vacuum' operation. The circuit's power requirements would also be managed effectively, with capacitors stabilizing the voltage input to the microcontroller, resulting in a safe system against any power surges.

Software Related

The program demonstrates the logic behind the vacuum robot's functionality with the integration of both ultrasonic sensing and PIC16F877A. Upon initialization, the program sets up the LCD modules to provide real-time feedback on the robot's operational status, indicating whether it's "turning" or "moving forward." The main loop of the program continuously checks the status of an on/off switch. If the switch is turned off, indicating standby mode, the LCDs a message accordingly and ensure the motors are stopped until the switch is turned back on. Once the switch is on, the program proceeds with normal operation. During normal operation, the program reads data from a potentiometer connected to the microcontroller's analog-to-digital converter (ADC). This data is used to simulate a distance measurement, which is then compared to a predefined threshold (10cm). Based on this comparison, the program decides whether the robot should continue moving forward or turn left to avoid obstacles. The functionality of the robot is managed through PWM signals generated by the microcontroller, controlling the speed and direction of the motors. When moving forward, both motors are set to full speed, while turning left involves adjusting the speed of one motor to facilitate the turn.

III. Review of Related Literature and Studies

As technology continues to advance, the need to incorporate it to make a person's everyday life easier becomes more prevalent. The main aspect of this project is the development of miniature learning vacuum robots. These devices use sophisticated algorithms to understand and adapt to their surroundings. Their sensing ability, which is essential for navigation and interaction, is based on ultrasonic technology. The PIC16F877A microcontroller, or 'brain' of these machines, is fundamental to their operation. The implementation of these devices will not only increase a person's productivity but also immensely aid persons with disabilities.

This review of related literature intends to explore the design and implementation of miniature learning vacuum robots using ultrasonic sensing and the PIC16F877A microcontroller. It will examine the current state of research in this sector, including the benefits and challenges of various technologies, as well as how they are being merged to produce efficient and effective cleaning robots.

Patil (2023) has designed a dust-cleaning robot using an embedded system. The robot can be controlled both autonomously and through a smartphone application. The robot mainly uses Arduino nano, Ultrasonic sensor, and Internet of Things (IoT) technology for its operation. The robot uses an ultrasonic sensor to detect obstacles and walls, and the sensing range is determined by Arduino Nano programming. The ultrasonic sensor has a ranging accuracy of around 20 cm to 2 m and works well within the allowed range of 50 cm. The system cleans effectively with a vacuum cleaner and a wiper motor, and the Internet of Things manages this process [6].

Shariffudin et al. (2023), have also developed an IoT-enabled automatic vacuum cleaner. The robot that they have designed utilizes an Arduino Mega as its microcontroller and HC-SR0 ultrasonic sensors. Similar to Patil's (2023) design, the robot can be controlled both autonomously and through a smartphone application called Blynk. Another convenient feature is that the robot can still function even without the user as long as it's connected to Wi-Fi. To identify the sensor accuracy and consistency on the distances between obstacles and the vacuum robot, as well as the most efficient speed for the robot to move, Shariffudin et al conducted multiple experiments to collect data. The results show that the lower the speed of the robot, the lower the percentage average error of distance from the wall to the sensor [7].

Saravanan (2022), developed an automatic floor-cleaning robot that uses an Arduino Mega microcontroller, ultrasonic sensors, and an embedded microcontroller unit with a DC shield. A lead-acid battery was used for the robot's power supply to minimize the robot's cost while also increasing its mobility. The researchers also conducted experiments for the optimization of the robot. They made sure to keep the dimensions and weight to a minimum to ensure excellent navigation and movement [8].

Instead of a floor-cleaning robot, Salunke et al (2019) have designed a glass-cleaning robot for high-rise buildings. The automation circuit includes a power supply, an Arduino Uno as the microcontroller, ultrasonic sensors, a relay circuit, solenoid valves, pneumatic cylinders, vacuum generators, and suction cups. The ultrasonic sensors measure the distance between the glass surface and the sensor. Like the others, the authors conducted several experiments for the robot's optimization. The robot was tested under specific conditions, including a power supply of 2V DC/230V AC, a compressed air supply at 10 to 15 PSI, and a workspace that can be traversed between square meters to 1500 square meters. The glass cleaning robot uses less electricity compared to other existing cleaning robots. This is achieved by utilizing the pneumatic solutions mounted on the robot. Specifically, the power consumption is as low as 200 watts/hour [9].

Ambadkar et al. (2023), not only utilized IoT for their smart cleaner, but also artificial intelligence (AI). The system comprises three ultrasonic sensors, and an Arduino Uno microcontroller, similar to Salunke et al. (2019). The robot can be controlled autonomously or using hand gestures detected by an accelerometer [10].

Jijesh et al. (2019) developed a vacuum cleaning robot operated by an Atmega328P microprocessor and equipped with IR sensors to identify obstructions. The title of the paper where they presented the robot is 'Swachh Robo One's Cleanliness Identity'. The robot can clean in several modes, including zigzag, spiral, and random patterns. The zigzag path provides total coverage, but the spiral and random paths are faster but may miss some locations. It can also clean a 100m*100m area in 2.5 minutes automatically and 20.6 minutes manually. Automatic mode uses less battery than manual mode [11].

Silkson et al. (2022) created a robot that functions as both a lawn mower and a vacuum cleaner. They specifically designed a solar-powered automatic lawn mower with a vacuum cleaner. They employed an Arduino Uno microcontroller and ultrasonic sensors, as did Salunke et al. (2019) and Ambedkar et al. (2023). The authors found that solar-powered lawnmowers and vacuum cleaners are feasible alternatives to fuel-efficient lawnmowers and vacuum cleaners and that they help to reduce greenhouse gas emissions [12].

Overall, The academic work covered in this paper demonstrates the critical importance of microcontrollers in the development of miniature learning vacuum robots. The majority of the studies conducted used Arduino microcontrollers, which have gained favor because of their ease of use and strong support network. However, this study deviates from the norm by adopting a PIC16F877A microcontroller. This microcontroller has various advantages, including robustness, versatility, and the capacity to work at faster clock speeds, which may improve the vacuum robot's performance. As the researchers continue to investigate the capabilities of the PIC16F877A microcontroller, it is expected that their findings will add to the current body of knowledge and open the way for new inventive applications of this technology in the field of autonomous cleaning robots. Future studies could focus on further refining the utilization of the PIC16F877A microcontroller to increase the robots' power efficiency and navigation capabilities.

IV. Significance of the Project

The significance of the study can be divided into three main segments: Affordability, Innovation, and Practicality.

Beginning with affordability, the increasing popularity of home automation, and the rise of autonomous cleaning devices, affordability is an important factor that needs to be considered when handling product creation and design. The study covers this aspect by focusing on the design and implementation of a cost-effective miniature learning vacuum robot. Thus, by prioritizing affordability, the research aims to make home automation solutions more accessible to everyday users. Moreover, by incorporating cost-effective materials and technologies, the study sets a possibility for future endeavors in the realm of affordable home automation.

Second would be the technological innovation that comes with the study. The research aims to contribute to the field by presenting a viable alternative that prioritizes both affordability and functionality. Along with this, building upon the work of past researchers, particularly with the use of ultrasonic sensor-based obstacle detection, the research has an existing foundation for enhancing and adding functionality.

Lastly, practical implementation and application add to the significance of the current study mainly due to the specific components used for the circuit. The integration of hardware components into a compact design, along with programming the microcontroller using MikroC, demonstrates a practical approach to developing an autonomous cleaning device. The proposed robot's ability to navigate independently is also a key aspect to take into consideration along with the ability for obstacle avoidance and cleanliness maintenance while remaining cost-efficient. Furthermore, by focusing on real-world usability and reliability, the study ensures that the developed solution is not just theoretically applicable but also practically feasible.

V. Recommendations

In the pursuit of advancing autonomous cleaning devices, this study identifies several key areas for future research and development that could substantially enhance the functionality, user experience, and market viability of vacuum robots. Firstly, the integration of advanced sensing technologies, such as infrared (IR) sensors and Light Detection and Ranging (LiDAR), is proposed to complement existing ultrasonic sensors.

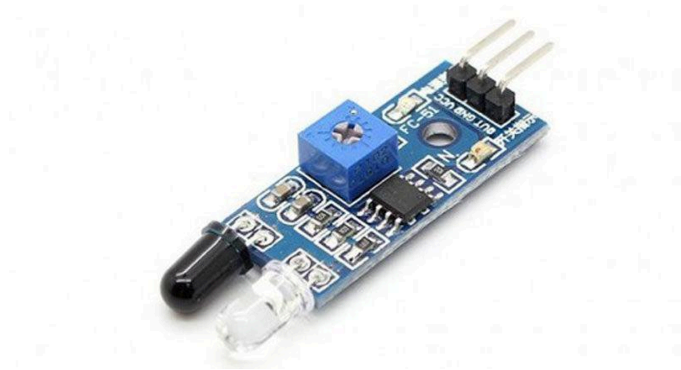

Figure 6. A common IR Proximity Sensor [13]

This multi-sensor approach aims to bolster the robot's navigation accuracy and environmental awareness. Secondly, the development of adaptive cleaning algorithms is highlighted as a critical improvement. By moving beyond simple path-following algorithms and employing machine learning techniques, the robot could dynamically adapt its cleaning strategy to the specifics of its environment. Optimizing the robot's energy consumption through the use of energy-efficient motors and the implementation of algorithms that minimize unnecessary movements could significantly extend its operational duration between charges.

VI. Conclusion

The successful design and deployment of the small learning vacuum robot, which uses the PIC16F877A microcontroller and ultrasonic sensing, have met the set goals. The combination of these elements has enabled the creation of an affordable yet effective self-operating cleaning device, furthering the progress of home automation technology.

Through careful design and execution, the PIC16F877A microcontroller was able to effectively manage the robot’s functions. The achievement of this initial PIC-based design highlights the potential of solutions based on microcontrollers in creating practical and accessible home automation devices. Consequently, it sets the stage for more exploration and innovation in this area, spurring future research and development efforts to build on this groundwork.

In conclusion, the development of the initial PIC-based vacuum robot represents a significant step in the pursuit of affordable and functional home automation solutions, demonstrating the viability and efficiency of using microcontroller technology for practical applications.

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Their friends and peers served as reminders to maintain determination and inspired them to push and persevere with the completion of this study.

The De La Salle University is an outlet for the zest and thirst for knowledge of the researchers and to educate the researchers on the basics to handle experiments of this caliber.

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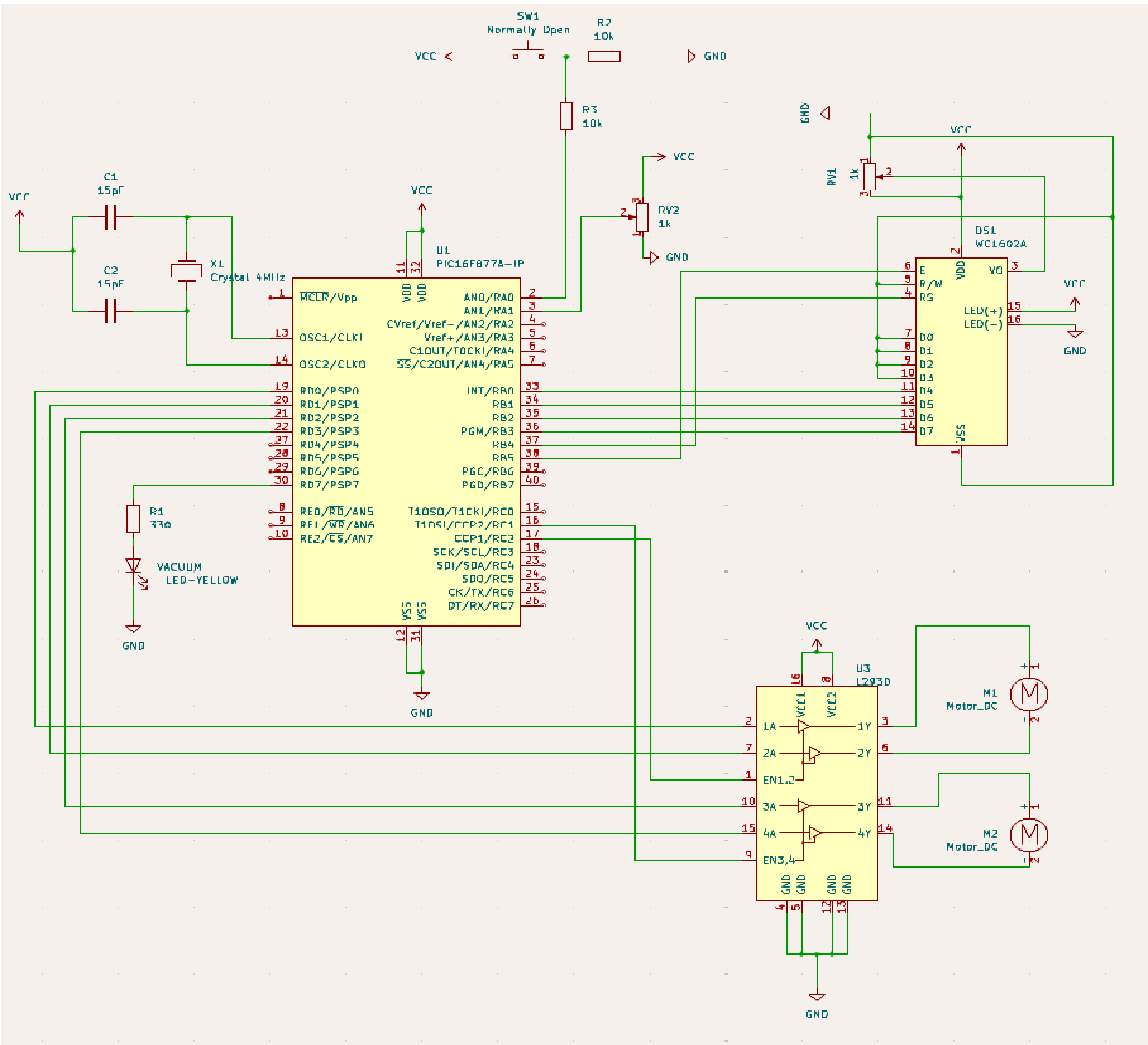
Appendix

Schematic Diagram:



Code:

C/C++

```
// Include necessary libraries

#include <stdint.h>



// LCD module connections

sbit LCD_RS at RB_bit;

sbit LCD_EN at RB5_bit;

sbit LCD_D at RB0_bit;

sbit LCD_D5 at RB1_bit;

sbit LCD_D6 at RB2_bit;

sbit LCD_D7 at RB3_bit;

sbit LCD_RS_Direction at TRISB_bit;

sbit LCD_EN_Direction at TRISB5_bit;

sbit LCD_D_Direction at TRISB0_bit;

sbit LCD_D5_Direction at TRISB1_bit;

sbit LCD_D6_Direction at TRISB2_bit;

sbit LCD_D7_Direction at TRISB3_bit;

// End LCD module connections



// Define L293D motor driver connections and on/off switch

#define IN1 PORTD.F0

#define IN2 PORTD.F1

#define IN3 PORTD.F2

#define IN PORTD.F3

#define EN1 CCP1CON // PWM1 controls EN1 (speed for motor 1)

#define EN2 CCP2CON // PWM2 controls EN2 (speed for motor 2)

#define VACUUM_LED PORTD.F7

#define ON_OFF_SWITCH PORTA.F0
```

```
#define MAX_ADC_VALUE 1023  // Max ADC value for 10-bit ADC

#define MAX_DISTANCE 100    // Max distance in cm


// Function declarations

void setup();

void displayStatus(char *status, char *distance);

void InitPWM();

void moveForward();

void turnLeft();

void stopMotors();

void checkOnOffSwitch();

unsigned int readPotentiometer(); // Function to read potentiometer value


void main() {

    setup();

    Lcd_Init();  // Initialize LCD

    while (1) {

        if(PORTA.F0 == 0) {  // Check if the enable switch is off

            Lcd_Cmd(_LCD_CLEAR);

            Lcd_Out(1, 1, "Device on standby");

            stopMotors(); // Make sure motors are not running

            while(PORTA.F0 == 0) { // Stay here as long as the switch is off

                Delay_ms(100);

            }

        } else {

            checkOnOffSwitch(); // If the switch is on, proceed with normal operation

        }

    }

}
```

```
}


void setup() {
       TRISA.F0 = 1; // Set RA0/AN0 as input
        TRISA = 0xFF; // Configure PORTA as input
        TRISD = 0;    // Configure PORTD as output
        PORTD = 0;    // Initialize PORTD to low

        Lcd_Init(); // Initialize LCD
        Lcd_Cmd(_LCD_CLEAR); // Clear LCD
        Lcd_Cmd(_LCD_CURSOR_OFF); // Turn cursor off

        InitPWM(); // Initialize PWM for motor control
        ADC_Init();
}

unsigned int readPotentiometer() {
    unsigned int adcValue;
    ADCON0 = 0x09; // Select AN2 channel, turn on ADC module
    ADCON0.GO_DONE = 1; // Start conversion
    while(ADCON0.GO_DONE); // Wait for conversion to finish
    adcValue = (ADRESH << 8) + ADRESL; // Read ADC result
    return adcValue;
}

void checkOnOffSwitch() {
        char txt[7];
        unsigned int adcValue;
        unsigned int simulatedDistance;
```

```
        adcValue = readPotentiometer(); // Read the potentiometer value
        simulatedDistance = (adcValue * MAX_DISTANCE) / MAX_ADC_VALUE; // Convert to distance

        IntToStr(simulatedDistance, txt); // Convert distance to string
        Ltrim(txt); // Trim leading spaces

        // Update status based on distance
        if (simulatedDistance < 10) { // If distance is less than 10 cm
        displayStatus("Turning", txt);
        turnLeft(); // Turn the Device left
        } else {
        displayStatus("Moving Forward", txt);
        moveForward(); // Move the Device forward
        }
        Delay_ms(500); // Add a delay for simulation purposes
}

void displayStatus(char *status, char *distance) {
        Lcd_Cmd(_LCD_CLEAR);
        Lcd_Out(1, 1, status);
        Lcd_Out(2, 1, "Distance: ");
        Lcd_Out(2, 11, distance);
        Lcd_Out(2, 1, "cm");
}



void InitPWM() {
```

```
        Pwm1_Init(5000);

        Pwm1_Start();

        Pwm2_Init(5000);

        Pwm2_Start();

}


void moveForward() {

        Pwm1_Set_Duty(255); // Full speed

        Pwm2_Set_Duty(255); // Full speed

        IN1 = 1;

        IN2 = 0;

        IN3 = 1;

        IN = 0;

        VACUUM_LED = 1; // Vacuum LED on indicating moving forward

}


void turnLeft() {

        Pwm1_Set_Duty(128); // Half speed to turn

        Pwm2_Set_Duty(255); // Full speed for other side

        IN1 = 0;

        IN2 = 1;

        IN3 = 1;

        IN = 0;

        VACUUM_LED = 1;

}


void stopMotors() {

        Pwm1_Set_Duty(0);

        Pwm2_Set_Duty(0);
```

```
        VACUUM_LED = 0; // Turn off Vacuum LED
}



        IntToStr(simulatedDistance, txt); // Convert distance to string
        Ltrim(txt); // Trim leading spaces

        // Update status based on distance
        if (simulatedDistance < 10) { // If distance is less than 10 cm
        displayStatus("Turning", txt);
        turnLeft(); // Turn the Device left
        } else {
        displayStatus("Moving Forward", txt);
        moveForward(); // Move the Device forward
        }
        Delay_ms(500); // Add a delay for simulation purposes
}

void displayStatus(char *status, char *distance) {
        Lcd_Cmd(_LCD_CLEAR);
        Lcd_Out(1, 1, status);
        Lcd_Out(2, 1, "Distance: ");
        Lcd_Out(2, 11, distance);
        Lcd_Out(2, 1, "cm");
}

void InitPWM() {
        Pwm1_Init(5000);
        Pwm1_Start();
```

```
        Pwm2_Init(5000);

        Pwm2_Start();

}
```