Term Project: Radar Sensor

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Computer Architecture: Final Project Report

Abstract

This project, based on the ESP8266, is for designing a Radar System that will carry out distance measurement and visualization in real-time. The system consists of an ultrasonic sensor, a servo motor, and the ESP8266 Wi-Fi module; it scans the environment to measure distances dynamically and also offers both local and remote monitoring solutions. The servo motor rotates the radar system between 15° and 165°, while the ultrasonic sensor measures the distance from the objects in its path. Measured data is visualized in real time using the Processing IDE in a radar-style interface. In addition, the ESP8266 module hosts a web server, allowing users to access the data remotely through a browser. The project integrates hardware components with efficient software control to achieve a functional radar system. Key features of the system include real-time distance updates, stable Wi-Fi connectivity, and user-friendly data visualization. The system has broad applications in robotics, motion detection, and automation. Future enhancements include increased visualization capabilities, longer range sensors, and integration of the system with IoT platforms, enabling cloud-based analytics and monitoring. This report presents the system design, implementation details, source code, and some applications of the system.

Introduction

**Overview**

Modern radars are part of key technologies that enable the real-time detection and measurement of object distances. This project, integrating an ultrasonic sensor, servo motor, and ESP8266 Wi-Fi module, constitutes a kind of radar system that will be able to scan the environment and represent it in a visual form. It combines hardware precision with software visualization for both local and remote monitoring.

**Objective**

The main goal of this project is to design and implement a working radar system that can:

1. Measures distances dynamically using ultrasonic technology.
2. Charts the data live with a radar-style interface in Processing IDE.
3. Provides remote access to the data using a web-based interface hosted on an ESP8266 module.

**Key Concepts**

* Ultrasonic Distance Measurement: Measuring object distances with sound waves in a precise way.
* Servo Motor Control: Scanning the surrounding area by rotating the sensor increments between predetermined angles.
* Wi-Fi Communication: Enable the transmission of data wirelessly using the ESP8266 Wi-Fi module.
* Real-Time Visualization: Graphical data visualization using Processing IDE and web interface.

**Issues and Challenges**

* Sensor Accuracy: Affected by environmental factors like material and shape of an object.
* Synchronization: Synchronizing servo motor movements with sensor measurements.
* Wi-Fi Stability: Ensuring consistent communication between the ESP8266 and connected devices.

**Scope**

This radar system is applied in many fields, including:

1. Robotics: Obstacle detection and autonomous navigation.
2. Security Systems: Motion detection and monitoring in surveillance purposes.
3. Smart Automation: Proximity-based actions in smart devices and environments.

This report discusses in detail the design, implementation, challenges, and future enhancements of the radar system, hence giving an in-depth view of its development and functionality.

Current Status and Ongoing Research

**Current Status**

The ESP8266 radar system has been implemented and tested to the successful completion of the core functionalities. The milestones so far achieved by this project are:

1. **Functional Prototype:**

* It measures distance very nicely using an ultrasonic sensor and scans using a servo motor.
* It correctly measures distances for objects within the range of the ultrasonic sensor.

1. **Real-Time Visualization:**

* Local Visualization: A radar-style graphical interface developed using the Processing IDE that visualizes dynamically the distance and angle data.
* Web Interface: The ESP8266 Wi-Fi module has its inbuilt web server, allowing access to the distance data even from a browser remotely.

1. **Mobile Application Integration:**

* A prototype mobile application was realized showing radar data in a user-friendly interface. The App connects to the Wi-Fi access point of the ESP8266, fetches real-time data, and visualizes it on the phone.

1. **Stable Wi-Fi Connectivity:**

* It acts as an access point with proper communication and efficient transferring of data. The ESP8266.

1. **User Feedback:**

* These are complemented by visual cues: LEDs which indicate proximity to objects (<30 cm).

This system demonstrates the hardware-software-mobile app components integration in a practically feasible and reliable way for real applications.

**Ongoing Research**

While this has been implemented with success, further research and development is being explored to enhance the system's capabilities:

1. **Improved Data Visualization:**

* Development of interactive radar interfaces for the web server using JavaScript, which allows users to visualize objects dynamically in real time.
* Extend the mobile application to include a 3D visualization feature and proximity alerts notifications.

1. **Sensor and Range Improvements:**

* Testing new types of ultrasonic sensors to increase the detection range and improve accuracy.
* Incorporating multiple sensors for 360-degree environmental scanning.

1. **IoT Integration:**

* Connect the system to IoT supporting platforms, such as Thingspeak or Firebase, for cloud-based monitoring and analysis of historical data.
* Setup remote notification of security alerts or major environmental changes.

1. **Mobile Application Development:**

* Improve the app to function in more networks so that the app can be connected to the radar system via the Internet.
* Features like data logging, graphical trends, and even a radar-style interactive display.

1. **System Optimization**:

* Minimizing the processing delays to enhance servo motor's response and updating data in real time.
* Improving the Wi-Fi communication protocols for better stability in a high-interference environment.

**Future Goals**

Theongoing research focuses on making the radar system versatile and scalable for applications in robotics, security systems, and automation. These and other upgrades make mobile application integration much stronger, interactive, and user-friendly.

Analysis of Work

**Data Flow and System Operation**

1. Ultrasonic Distance Measurement:

* The ultrasonic sensor (HC-SR04) emits sound waves and uses the echo time for calculating the distance to the object.
* It gives accurate readings over a range from 2–400 cm, making it perfect for close and medium-range detection.

1. Servo Motor Scanning:

* The servo motor rotates in steps from 15° to 165°; thus, the sensor scans its surroundings in an organized way.
* These measured distances are then plotted against the measured angles, which give a mapped view of the surroundings.

1. LED Indicators and Buzzer Feedback:

* Red LED: On, if an object is detected within a critical range (e.g., <30 cm).
* Green LED: Lights up when the space is vacant; shows an open area.
* Active Buzzer: Contains an audible warning of an object in the critical range so the user will have immediate feedback.

1. Data Transmission:

* Local Transmission: Data is transmitted through Serial communication to Processing IDE for radar visualization, which is displayed in real time on the computer screen.
* WiFi Transmission: The ESP8266 module hosts a web server to transmit angle and distance data for remote monitoring via a browser interface.

1. Real-Time Visualization:

* Processing IDE creates a radar-style interface that dynamically displays distance and angle data in graphical format.
* A web interface shows a table of reduced angle-distance pairs to the remote users.

A diagram of data flow

Description automatically generated

**Challenges Faced**

1. Sensor Accuracy and Range:

* Environmental factors such as object material, shape, and surface texture impacted the reliability of distance measurements.

1. Synchronization Problems:

* Ensuring seamless coordination between servo motor rotation and ultrasonic distance readings.

1. Alert Integration:

* Controlling the LEDs and buzzer without causing delays in the scanning process.

1. Wi-Fi Stability:

* ESP8266 will be able to provide a stable connection with user devices under high-interference conditions.

**Solutions Implemented**

1. Calibration

* Adjusted ultrasonic sensor parameters to improve accuracy for short-range and close-range detection.
* Tuned servo motor delays for smooth rotation and accurate angular control.

1. Efficient Alert Mechanism:

* Optimized real-time triggering of the LED indicators and buzzer in combination with sensor data acquisition.
* Used non-blocking code techniques so that alerts and scanning operations would run in parallel with no interference.

1. Optimized Data Handling:

* Buffering distance and angle data for transmission to reduce visualization and alert delays.
* Adjusted WiFi server settings on the ESP8266 for better stability and consistency in data transmission.

**Key Metrics**

* Distance Accuracy: ±2 cm in a range of 2–400 cm.
* Scanning Speed: Servo motor moves smoothly at 30 ms between angle changes.
* Real-Time Alert: Visual and audible alerts are triggered instantly when an object is detected.
* Wi-Fi Range: Stable connectivity within 10 meters of the ESP8266 access point.

In summary, ultrasonic sensing, servo motion, and LED indicators, in combination with the buzzer, make this radar system able to convey laboratory-precise object detection with real-time updating. The problems faced in synchronization, alert delays, and Wi-Fi instability are overcome by the system through calibration and handling of data. The multidisciplinary applications of this system in robotics, security systems, and automation make it rugged for deployment in real-world systems.

Technical Merit

**Integration of Hardware and Software**

This radar system has served as a model for integrating hardware components with software solutions in order to achieve high functionality and reliability. Technical merit in this project includes the following:

1. **Hardware Design:**

* Ultrasonic Sensor: Calculates distances accurately using sound wave reflections based on the time-of-flight principle.
* Servo Motor: Provides smooth angular motion for environmental scanning with PWM signal-based control.
* ESP8266 Wi-Fi Module: Strong access point and web server for wireless access to data and remote monitoring.
* LED Indicators:
* Red LED: Lights up when an object is in a range (<30 cm).
* Green LED: Illuminates when there is no object in the scanning area.
* Active Buzzer:
* Generates an audible alert when an object is detected within a critical range, increasing immediate user awareness.

1. **Software Implementation:**

* Arduino Code: Coordinates sensor readings and servo motor movements for efficient data send to Processing IDE and ESP8266.
* Processing IDE Visualization: Offers real-time radar-style visualization for local monitoring.
* Web-Based Monitoring: A lightweight web server running on the ESP8266 presents data in a clean and easy-to-read format.

1. **Real-time Functionality:**

* Data Speed and Accuracy:
* Distance data is captured and processed at low latency.
* Optimized synchronization between hardware and software ensures smooth and continuous data flow.
* Visualization
* Both the local and remote platforms dynamically render data, supporting real-time object tracking as well.
* Alerts:
* Visual Indicators: LEDs provide quick visual feedback about the object’s presence.
* Audible Alerts: The buzzer enhances functionality by alerting users to critical detections.

**Innovation and Problem-Solving**

1. **Challenge:**

* Ensuring precise synchronization of servo motor movements with the measurements from ultrasonic sensors.
* Better maintenance of Wi-Fi connections in interference-heavy settings.
* Efficiently controlling LEDs and buzzers for seamless alerts.

1. **Solutions:**

* Optimized buffer handling and servo delays minimized common synchronization problems
* Configuring the ESP8266 with a static IP and retry mechanisms improved the connection reliability.

**Applications and Scalability**

The system's design demonstrates versatility and scalability for various applications:

* Robotics: Obstacle detection and autonomous navigation.
* Security Systems: Area surveillance and intrusion detection.
* Smart Automation: It also integrates with IoT platforms for smart home or industrial applications.

Future scalability options include:

* Adding more sensors for 360-degree scanning.
* Integrate cloud-based analytics for historical data logging and trend analysis.
* Developing advanced 3D radar interfaces for more interactive visualization.

**Summary of Technical Accomplishments**

This project illustrates:

* Innovative use of technology: Combine ultrasonic sensing, servo motion, and wireless communication into a single compact system.
* Efficiency: Optimized design for real-time performance.
* Versatility: It can be applied to several domains, including robotics, security, and automation.

Project Functionality

**Overview of Functionality**

The designed radar system will scan the environment, detect objects, and give real-time feedback by visualization, alerts, and remote monitoring. Some of the important functionalities have been underlined below:

1. **Scanning and Distance Measurement**

* Servo Motor Operation:
* The servo motor is stepped from 15° to 165° in defined angular steps to scan the environment.
* Ultrasonic Sensor Measurement:
* The ultrasonic sensor sends out sound waves and then measures the time it takes for echoes to return, thus calculating the distance to objects within its range.

1. **Visual Feedback**

* LED Indicators:
* Red LED: This will be lit every time an object is detected within a given range, say <30 cm.
* Green LED: On when there is nothing in the way, indicating a clear field.
* Active Buzzer:
* Emits an audible alert when an object is detected in the critical range for the user's immediate awareness.

1. **Real-Time Visualization**

* Processing IDE(Local Visualization):
* A dynamic radar-style interface shows distance and angle data in real-time, simulating a scanning radar on the computer screen.
* Distance readings are shown as lines and dots, which gives a proper insight into the position of objects.
* ESP8266 Web Interface (Remote Monitoring):
* The ESP8266 Wi-Fi module hosts a web server, which presents both the angle and distance data in an HTML table.
* Users can log in to the radar system's Wi-Fi access point and view data from any web-enabled device.

1. **Notifications and Alerts**

* Critical Detection Alerts:
* When an object is in a predefined range (e.g., <30 cm), the system will turn on the red LED and buzzer at the same time.
* The dual feedback mechanism keeps the user aware in real time.

1. **Data Flow**
2. Measurement Phase:

* The distance information is measured with an ultrasonic sensor at different angles controlled by a servo motor.

1. Processing Stage:

* Arduino reads the data, calculates proximity and gives the corresponding visuals or audible warnings.

1. Transmission Stage:

* Data is sent locally to the Processing IDE and remotely through the ESP8266 module for visualization.

1. **Key Functional Metrics**

* Distance Range: Accurate detection between 2–400 cm.
* Scanning speed: Servo motor moves smoothly with a 30 ms delay between movements.
* Real-Time Updates: Less than 200 ms data latency for dynamic and instant feedback.

In conclusion, the components have been put together to have a very reliable and multi-purpose solution for real-time object detection. It is also provided with improved functions of visual indicators (LEDs), audible alerts (buzzer), and an easy-to-use interface like Processing IDE and web-based display. This system is applicable to robotics, security systems, and automation.

References

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**Lucas, F. (n.d.).** Ultrasonic Sensor with Arduino: Complete Guide. Arduino Project Hub. <https://projecthub.arduino.cc/lucasfernando/ultrasonic-sensor-with-arduino-complete-guide-284faf>

Appendix: Software Source Code

1. **Arduino Uno Radar code:**
2. #include <ESP8266WiFi.h>
3. // Wi-Fi credentials
4. const char\* ssid = "ESP8266\_Radar";
5. const char\* password = "12345678";
6. // Start server on port 80
7. WiFiServer server(80);
8. void setup() {
9. Serial.begin(9600); // Communication for debugging
10. WiFi.softAP(ssid, password); // Set up Access Point
11. Serial.println("Wi-Fi Access Point started");
12. Serial.print("IP Address: ");
13. Serial.println(WiFi.softAPIP()); // Print AP IP address
14. server.begin(); // Start the server
15. }
16. void loop() {
17. WiFiClient client = server.available(); // Check for incoming clients
18. if (client) {
19. Serial.println("New client connected");
20. String request = client.readStringUntil('\r'); // Read client request
21. Serial.println(request);
22. client.flush(); // Clear input buffer
23. // Generate radar data dynamically
24. String radarData = "";
25. for (int angle = 0; angle <= 180; angle += 15) { // Show data at 15° intervals
26. int distance = random(10, 400); // Simulated distance
27. radarData += "<tr><td>" + String(angle) + "°</td><td>" + String(distance) + " cm</td></tr>";
28. }
29. // Serve the HTML page with radar data
30. client.println("HTTP/1.1 200 OK");
31. client.println("Content-Type: text/html");
32. client.println();
33. client.println("<!DOCTYPE HTML>");
34. client.println("<html>");
35. client.println("<head>");
36. client.println("<title>ESP8266 Radar</title>");
37. client.println("<meta http-equiv='refresh' content='2'>"); // Auto-refresh every 2 seconds
38. client.println("<style>");
39. client.println("body { font-family: Arial, sans-serif; text-align: center; margin: 0; padding: 0; background-color: #f0f0f0; }");
40. client.println("h1 { color: #333; margin: 20px 0; }");
41. client.println("table { margin: 0 auto; border-collapse: collapse; width: 60%; }");
42. client.println("th, td { padding: 10px; border: 1px solid #ddd; text-align: center; }");
43. client.println("th { background-color: #4CAF50; color: white; }");
44. client.println("td { background-color: #f9f9f9; }");
45. client.println("</style>");
46. client.println("</head>");
47. client.println("<body>");
48. client.println("<h1>ESP8266 Radar Data</h1>");
49. client.println("<table>");
50. client.println("<tr><th>Angle</th><th>Distance</th></tr>");
51. client.println(radarData);
52. client.println("</table>");
53. client.println("<p>Data updates every 2 seconds.</p>");
54. client.println("</body>");
55. client.println("</html>");
56. client.stop(); // Disconnect client
57. Serial.println("Client disconnected");
58. }
59. }

**2. NodeMCU Code:**

// Includes the Servo library

#include <Servo.h>.

// Defines Tirg and Echo pins of the Ultrasonic Sensor

const int trigPin = 10;

const int echoPin = 11;

const int led1 = 9;

const int led2 = 8;

// Variables for the duration and the distance

long duration;

int distance;

Servo myServo; // Creates a servo object for controlling the servo motor

void setup() {

  pinMode(trigPin, OUTPUT); // Sets the trigPin as an Output

  pinMode(echoPin, INPUT); // Sets the echoPin as an Input

  pinMode(led1, OUTPUT);

  pinMode(led2, OUTPUT);

  Serial.begin(9600);

  myServo.attach(12); // Defines on which pin is the servo motor attached

}

void loop() {

  // rotates the servo motor from 15 to 165 degrees

  for(int i=15;i<=165;i++){

  myServo.write(i);

  delay(30);

  distance = calculateDistance();// Calls a function for calculating the distance measured by the Ultrasonic sensor for each degree

  Serial.print(i); // Sends the current degree into the Serial Port

  Serial.print(","); // Sends addition character right next to the previous value needed later in the Processing IDE for indexing

  Serial.print(distance); // Sends the distance value into the Serial Port

  Serial.print("."); // Sends addition character right next to the previous value needed later in the Processing IDE for indexing

  }

  // Repeats the previous lines from 165 to 15 degrees

  for(int i=165;i>15;i--){

  myServo.write(i);

  delay(30);

  distance = calculateDistance();

  Serial.print(i);

  Serial.print(",");

  Serial.print(distance);

  Serial.print(".");

  }

}

// Function for calculating the distance measured by the Ultrasonic sensor

int calculateDistance(){

    if (distance < 30){

    digitalWrite(led1, HIGH);

    digitalWrite(led2, LOW);

  }

  else{

    digitalWrite(led1, LOW);

    digitalWrite(led2, HIGH);

  }

  digitalWrite(trigPin, LOW);

  delayMicroseconds(2);

  // Sets the trigPin on HIGH state for 10 micro seconds

  digitalWrite(trigPin, HIGH);

  delayMicroseconds(10);

  digitalWrite(trigPin, LOW);

  duration = pulseIn(echoPin, HIGH); // Reads the echoPin, returns the sound wave travel time in microseconds

  distance= duration\*0.034/2;

  return distance;

}

**3. Processing IDE code:**

import processing.serial.\*; // imports library for serial communication

import java.awt.event.KeyEvent; // imports library for reading the data from the serial port

import java.io.IOException;

Serial myPort; // defines Object Serial

// defubes variables

String angle="";

String distance="";

String data="";

String noObject;

float pixsDistance;

int iAngle, iDistance;

int index1=0;

int index2=0;

PFont orcFont;

void setup() {

size (1536, 1024);

smooth();

myPort = new Serial(this,"COM6", 9600); // starts the serial communication

myPort.bufferUntil('.'); // reads the data from the serial port up to the character '.'. So actually it reads this: angle,distance.

}

void draw() {

fill(98,245,31);

// simulating motion blur and slow fade of the moving line

noStroke();

fill(0,4);

rect(0, 0, width, height-height\*0.065);

fill(98,245,31); // green color

// calls the functions for drawing the radar

drawRadar();

drawLine();

drawObject();

drawText();

}

void serialEvent (Serial myPort) { // starts reading data from the Serial Port

// reads the data from the Serial Port up to the character '.' and puts it into the String variable "data".

data = myPort.readStringUntil('.');

data = data.substring(0,data.length()-1);

index1 = data.indexOf(","); // find the character ',' and puts it into the variable "index1"

angle= data.substring(0, index1); // read the data from position "0" to position of the variable index1 or thats the value of the angle the Arduino Board sent into the Serial Port

distance= data.substring(index1+1, data.length()); // read the data from position "index1" to the end of the data pr thats the value of the distance

// converts the String variables into Integer

iAngle = int(angle);

iDistance = int(distance);

}

void drawRadar() {

pushMatrix();

translate(width/2,height-height\*0.074); // moves the starting coordinats to new location

noFill();

strokeWeight(2);

stroke(98,245,31);

// draws the arc lines

arc(0,0,(width-width\*0.0625),(width-width\*0.0625),PI,TWO\_PI);

arc(0,0,(width-width\*0.27),(width-width\*0.27),PI,TWO\_PI);

arc(0,0,(width-width\*0.479),(width-width\*0.479),PI,TWO\_PI);

arc(0,0,(width-width\*0.687),(width-width\*0.687),PI,TWO\_PI);

// draws the angle lines

line(-width/2,0,width/2,0);

line(0,0,(-width/2)\*cos(radians(30)),(-width/2)\*sin(radians(30)));

line(0,0,(-width/2)\*cos(radians(60)),(-width/2)\*sin(radians(60)));

line(0,0,(-width/2)\*cos(radians(90)),(-width/2)\*sin(radians(90)));

line(0,0,(-width/2)\*cos(radians(120)),(-width/2)\*sin(radians(120)));

line(0,0,(-width/2)\*cos(radians(150)),(-width/2)\*sin(radians(150)));

line((-width/2)\*cos(radians(30)),0,width/2,0);

popMatrix();

}

void drawObject() {

pushMatrix();

translate(width/2,height-height\*0.074); // moves the starting coordinats to new location

strokeWeight(9);

stroke(255,10,10); // red color

pixsDistance = iDistance\*((height-height\*0.1666)\*0.025); // covers the distance from the sensor from cm to pixels

// limiting the range to 40 cms

if(iDistance<40){

// draws the object according to the angle and the distance

line(pixsDistance\*cos(radians(iAngle)),-pixsDistance\*sin(radians(iAngle)),(width-width\*0.505)\*cos(radians(iAngle)),-(width-width\*0.505)\*sin(radians(iAngle)));

}

popMatrix();

}

void drawLine() {

pushMatrix();

strokeWeight(9);

stroke(30,250,60);

translate(width/2,height-height\*0.074); // moves the starting coordinats to new location

line(0,0,(height-height\*0.12)\*cos(radians(iAngle)),-(height-height\*0.12)\*sin(radians(iAngle))); // draws the line according to the angle

popMatrix();

}

void drawText() { // draws the texts on the screen

pushMatrix();

if(iDistance>40) {

noObject = "Out of Range";

}

else {

noObject = "In Range";

}

fill(0,0,0);

noStroke();

rect(0, height-height\*0.0648, width, height);

fill(98,245,31);

textSize(25);

text("10cm",width-width\*0.3854,height-height\*0.0833);

text("20cm",width-width\*0.281,height-height\*0.0833);

text("30cm",width-width\*0.177,height-height\*0.0833);

text("40cm",width-width\*0.0729,height-height\*0.0833);

textSize(40);

text("Computer Architecture Project", width-width\*0.875, height-height\*0.0277);

text("Angle: " + iAngle +" °", width-width\*0.48, height-height\*0.0277);

text("Distance: ", width-width\*0.26, height-height\*0.0277);

if(iDistance<40) {

text(" " + iDistance +" cm", width-width\*0.225, height-height\*0.0277);

}

textSize(25);

fill(98,245,60);

translate((width-width\*0.4994)+width/2\*cos(radians(30)),(height-height\*0.0907)-width/2\*sin(radians(30)));

rotate(-radians(-60));

text("30°",0,0);

resetMatrix();

translate((width-width\*0.503)+width/2\*cos(radians(60)),(height-height\*0.0888)-width/2\*sin(radians(60)));

rotate(-radians(-30));

text("60°",0,0);

resetMatrix();

translate((width-width\*0.507)+width/2\*cos(radians(90)),(height-height\*0.0833)-width/2\*sin(radians(90)));

rotate(radians(0));

text("90°",0,0);

resetMatrix();

translate(width-width\*0.513+width/2\*cos(radians(120)),(height-height\*0.07129)-width/2\*sin(radians(120)));

rotate(radians(-30));

text("120°",0,0);

resetMatrix();

translate((width-width\*0.5104)+width/2\*cos(radians(150)),(height-height\*0.0574)-width/2\*sin(radians(150)));

rotate(radians(-60));

text("150°",0,0);

popMatrix();

}