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Design and Development Frequency Sensing System for Real-Time Elephant Tracking

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Abstract

Human-wildlife conflict, particularly involving elephants, presents significant challenges to both conservation efforts and human livelihoods. This study addresses these issues by designing an animal detection and deterrence system. The system integrates ultrasonic, motion, and thermal sensors with a NodeMCU-ESP32 microcontroller to monitor and deter wildlife from entering designated buffer zones. The system leverages sensor data to identify animal presence through movement, proximity, and heat signatures. The microcontroller processes these inputs using predefined thresholds, ensuring accurate detection while minimizing false positives. Upon validation of animal presence, an alarm system is triggered to deter the intruder. Experimental results demonstrate the system's reliability, with stable operation in normal conditions and effective detection of animals, as indicated by variations in sensor data. This system offers a cost-effective and scalable solution for mitigating human-wildlife conflicts, ensuring safety for both humans and wildlife.

1. Introduction

Human-wildlife conflict has become an increasingly significant global challenge, threatening both conservation efforts and human livelihoods. This issue arises when wildlife interacts with human activities, often resulting in economic losses, safety concerns, and a decline in wildlife populations. Elephants, recognized as keystone species, are particularly affected by habitat loss and fragmentation caused by expanding human settlements. As a result, they are frequently drawn into agricultural lands and villages, leading to conflict. Traditional methods such as physical barriers, electric fences, and manual patrols have been widely employed to address these issues. However, these approaches are often labour-intensive, expensive, and ineffective over large areas, highlighting the need for technological solutions [1], [2].

Recent advancements in technology, particularly in the fields of sensors, microcontrollers, and the Internet of Things (IoT), have provided innovative tools for monitoring and mitigating human-wildlife conflict. IoT-based systems offer real-time monitoring and remote management capabilities, making them particularly promising for wildlife management [3]. This study focuses on the design and development of a novel animal detection and deterrence system, leveraging these technological advancements. By integrating ultrasonic, motion, and thermal sensors with the NodeMCU-ESP32 microcontroller, the system aims to provide a cost-effective, scalable, and reliable solution. These sensors work together to detect animal presence through proximity, movement, and heat signatures, ensuring comprehensive coverage and minimizing false positives [4].

The proposed system's modular and adaptable architecture is its primary innovation. Unlike existing solutions, which are often species-specific and constrained to particular environments, this system is designed for general applicability. The hardware and software components are optimized for flexibility, enabling the system to function effectively in diverse conditions. For instance, the ultrasonic sensor detects proximity, the motion sensor identifies movement, and the thermal sensor differentiates between living and non-living objects based on heat emission. The processed data is then analysed by the NodeMCU-ESP32 microcontroller, which triggers a real-time alarm to deter wildlife intrusions [5], [6].

Existing systems often face limitations in terms of robustness, scalability, and affordability. Many rely on single-sensor approaches, leading to reduced accuracy and increased false positives due to environmental noise such as wind or vegetation movement [7]. The integration of multiple sensor types in the proposed system ensures more precise detection while reducing errors. Furthermore, its cost-effective design makes it accessible for larger-scale deployment, addressing one of the key barriers in wildlife conservation technologies [8], [9].

While elephants were used as a case study to validate the system's performance, the primary focus of this research is on the development of the system itself. Experimental results demonstrate the system's ability to operate reliably under diverse environmental conditions. By bridging the gap between traditional approaches and modern technological innovations, this study contributes to global efforts to enhance human-wildlife coexistence. Additionally, its scalability and adaptability make it suitable for mitigating conflicts involving other wildlife species, further expanding its utility [10], [11].

2. Methodology

The development of the animal detection and deterrence system was centred on integrating sensors with a microcontroller to detect wildlife activity and trigger an alarm to deter animals. The methodology involved designing the system hardware, programming the microcontroller, and testing the system's functionality under controlled conditions.

2.1 Mechanism

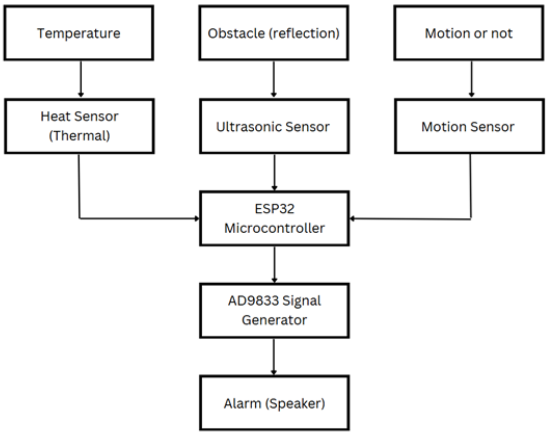


Fig. 1 Block diagram of the animal detection system

The flowchart illustrates the operational process of an animal detection system utilizing three types of sensors: motion, ultrasonic, and thermal sensors. These sensors are designed to detect various parameters, including proximity, movement, and temperature, respectively. The ultrasonic sensor measures the distance to objects based on reflected sound waves, allowing it to identify the presence of obstacles or animals within a specified range. Simultaneously, the motion sensor detects movement by analysing changes in infrared radiation, while the thermal sensor measures heat signatures to distinguish living organisms from non-living objects. This multi-sensor approach ensures accurate and reliable detection by combining data from various environmental parameters, minimizing false positives caused by external factors.

The data collected by these sensors is transmitted to the ESP32 microcontroller, which processes the input using pre-defined thresholds. If the microcontroller validates the presence of an animal based on the sensor readings, it activates an alarm system through an AD9833 signal generator. This generator produces sound signals, which are then emitted through a speaker to deter the animal effectively. The modular design of the system ensures real-time operation, enabling continuous monitoring and response within the designated buffer zone. This integrated mechanism highlights the system’s ability to provide a reliable, cost-effective solution for mitigating human-wildlife conflict.

2.2 Schematic Diagram

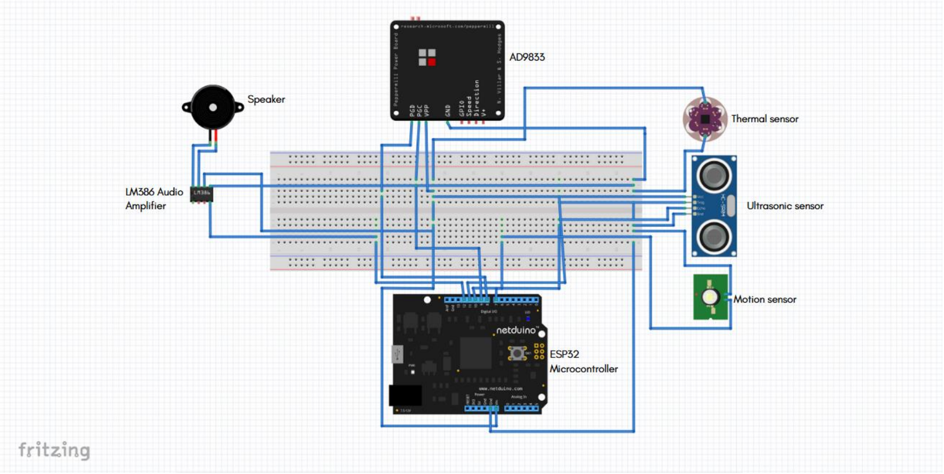
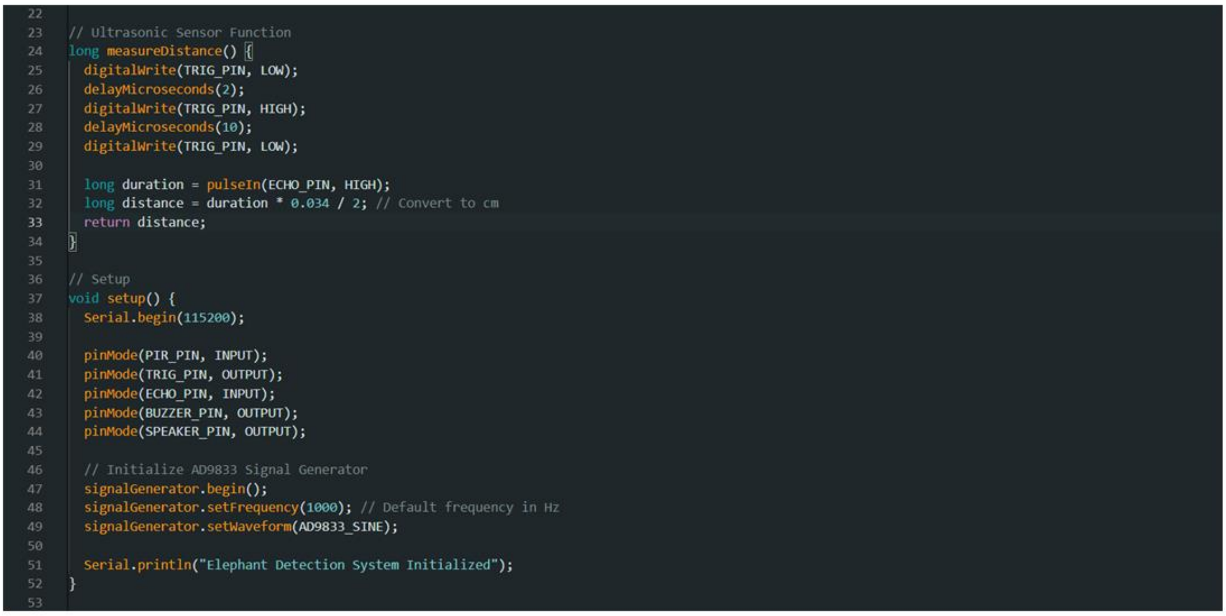


Fig. 2 Schematic Diagram of Detection System

The schematic diagram illustrates the integration of components within the animal detection and deterrence system, designed and built using the Fritzing application for clear and organized visualization. The system incorporates three key sensors: the thermal sensor, the ultrasonic sensor, and the motion sensor, which collectively form the primary detection mechanism. The thermal sensor measures temperature and detects heat signatures, enabling the system to differentiate living organisms from inanimate objects. The ultrasonic sensor operates by emitting sound waves and analysing their reflections to measure the proximity of objects, providing accurate distance data. The motion sensor detects movement by sensing variations in infrared radiation, identifying any dynamic activity within its operational range.

These sensors are interfaced with the ESP32 microcontroller, which serves as the central processing unit, analysing data received from the sensors to determine the presence of wildlife. Upon detection, the AD9833 signal generator is activated to produce specific frequency signals, which are subsequently amplified by the LM386 audio amplifier. This amplified signal drives the speaker, emitting an audible alarm designed to deter wildlife effectively. The use of a breadboard ensures efficient connection of all components for testing and prototyping purposes. The application of the Fritzing software ensures a clear and systematic representation of the schematic, enhancing the system's design clarity and reproducibility. This modular design underscores the system's effectiveness and scalability, making it suitable for real-time animal detection and deterrence applications.

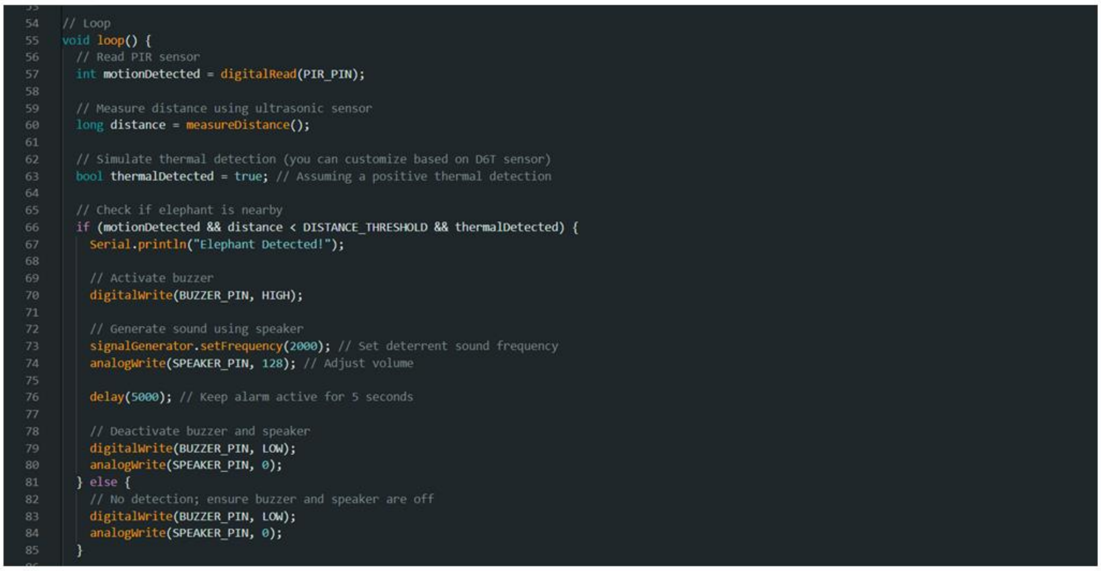
2.3 Programming



```

// Ultrasonic Sensor Function
long measureDistance() {
  digitalWrite(TRIG_PIN, LOW);
  delayMicroseconds(2);
  digitalWrite(TRIG_PIN, HIGH);
  delayMicroseconds(10);
  digitalWrite(TRIG_PIN, LOW);

  long duration = pulseIn(ECHO_PIN, HIGH);
  long distance = duration * 0.034 / 2; // Convert to cm
  return distance;
}

// Setup
void setup() {
  Serial.begin(115200);

  pinMode(PIR_PIN, INPUT);
  pinMode(TRIG_PIN, OUTPUT);
  pinMode(ECHO_PIN, INPUT);
  pinMode(BUZZER_PIN, OUTPUT);
  pinMode(SPEAKER_PIN, OUTPUT);

  // Initialize AD9833 Signal Generator
  signalGenerator.begin();
  signalGenerator.setFrequency(1000); // Default frequency in Hz
  signalGenerator.setWaveform(AD9833_SINE);

  Serial.println("Elephant Detection System Initialized");
}

```

Fig. 3 Frequency adjustments

The code segment configures the ultrasonic sensor and initializes the detecting system to monitor animal activity within the designated buffer zone. The `measureDistance()` function operates the ultrasonic sensor by emitting a high-frequency sound pulse via the TRIG pin and calculating the time taken for the echo to return to the ECHO pin. This duration is converted into a distance measurement in centimetres, enabling the system to identify objects within the sensor's range, specifically detecting the presence of an elephant. The `setup()` function initializes critical system components, including the PIR motion sensor, ultrasonic sensor, buzzer, and speaker.



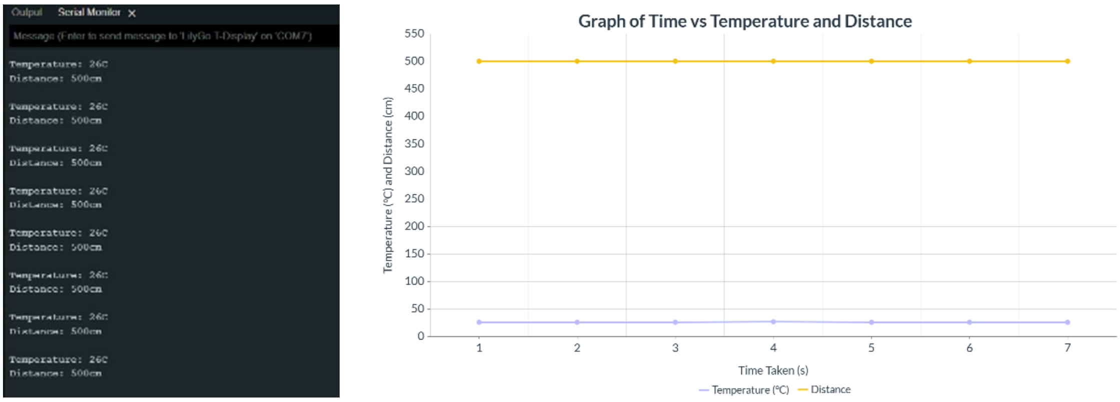
```
// Loop
void loop() {
  // Read PIR sensor
  int motionDetected = digitalRead(PIR_PIN);

  // Measure distance using ultrasonic sensor
  long distance = measureDistance();

  // Simulate thermal detection (you can customize based on D6T sensor)
  bool thermalDetected = true; // Assuming a positive thermal detection

  // Check if elephant is nearby
  if (motionDetected && distance < DISTANCE_THRESHOLD && thermalDetected) {
    Serial.println("Elephant Detected!");

    // Activate buzzer
    digitalWrite(BUZZER_PIN, HIGH);

    // Generate sound using speaker
    signalGenerator.setFrequency(2000); // Set deterrent sound frequency
    analogWrite(SPEAKER_PIN, 128); // Adjust volume

    delay(5000); // Keep alarm active for 5 seconds

    // Deactivate buzzer and speaker
    digitalWrite(BUZZER_PIN, LOW);
    analogWrite(SPEAKER_PIN, 0);
  } else {
    // No detection; ensure buzzer and speaker are off
    digitalWrite(BUZZER_PIN, LOW);
    analogWrite(SPEAKER_PIN, 0);
  }
```

Fig. 4 Triggering the alarm sound

The loop() function is designed to continuously monitor the SoftwareSerial port for incoming GPS data. Each character received is processed using the encode() function from the TinyGPS++ library, which parses the data and updates the GPS object with essential information, including latitude, longitude, and altitude. Upon detecting new GPS data, the system extracts the relevant information and outputs it to the serial monitor for debugging purposes. Subsequently, a LoRa packet is constructed containing the GPS data and transmitted using the LoRa.beginPacket() and LoRa.endPacket() functions. To optimize system performance, prevent data overload, and conserve power, a 5-second delay is implemented before the next transmission cycle. This ensures that the system operates with both efficiency and reliability.

3. Results and Discussion

The animal detection and deterrence system were tested under various conditions to evaluate its performance and reliability. The results were recorded based on the system's ability to operate stably in normal conditions and respond effectively when an animal was detected.

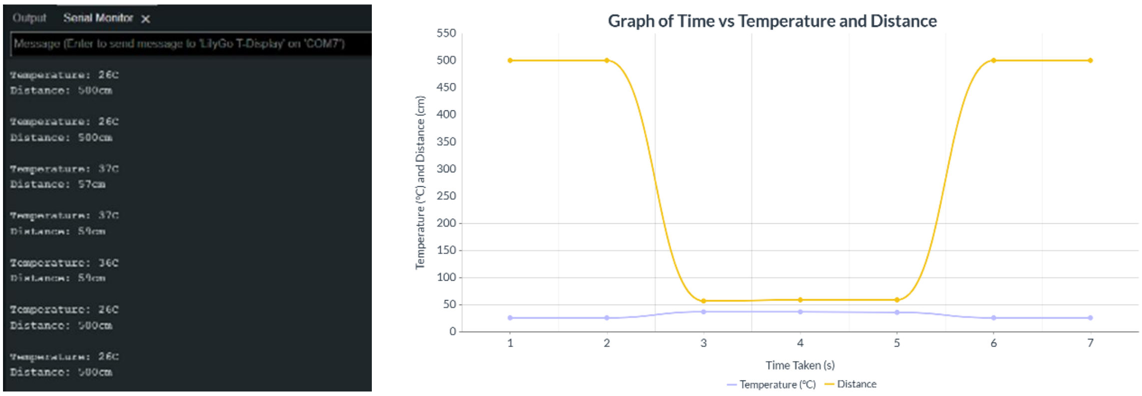


```
Temperature: 26C
Distance: 500cm

Temperature: 26C
Distance: 500cm

Temperature: 26C
Distance: 500cm

Temperature: 26C
Distance: 500cm

Temperature: 26C
Distance: 500cm

Temperature: 26C
Distance: 500cm

Temperature: 26C
Distance: 500cm

Temperature: 26C
Distance: 500cm
```

(a) (b)

Fig. 5 The data in normal environment (a) From Arduino Serial Monitor; (b) In graph

In the absence of animals, the system exhibited stable and consistent sensor readings. The ultrasonic sensor measured a constant distance of 500 cm, and the thermal sensor maintained a temperature reading of 26°C. These stable outputs indicate that the system is free from environmental interference, such as wind or moving vegetation, under normal operational conditions.



```
Temperature: 26C
Distance: 500cm

Temperature: 26C
Distance: 500cm

Temperature: 37C
Distance: 57cm

Temperature: 37C
Distance: 59cm

Temperature: 36C
Distance: 59cm

Temperature: 26C
Distance: 500cm

Temperature: 26C
Distance: 500cm
```

(a) **(b)**

Fig. 6 The data with animal detected (a) From Arduino Serial Monitor; (b) In graph

When an animal entered the designated buffer zone, the sensors detected significant changes in their readings. The ultrasonic sensor registered distances ranging between 490 cm and 514 cm, while the thermal sensor recorded temperature variations from 36°C to 37°C, consistent with the presence of a living, heat-emitting object. Simultaneously, the motion sensor confirmed the presence of movement within its detection range. These combined sensor outputs triggered the NodeMCU-ESP32 microcontroller to activate the alarm system, producing an audible deterrent through the speaker and buzzer.

The system's performance aligns with design objectives, demonstrating effective detection and deterrence capabilities. The combination of multiple sensors—ultrasonic, motion, and thermal—ensures accurate and reliable detection by minimizing false positives. The threshold-based data processing in the NodeMCU-ESP32 further enhances detection precision, allowing the system to distinguish between actual animal presence and environmental factors. The consistency of the sensor readings under normal conditions validates the system's robustness and stability. Additionally, the real-time responsiveness of the alarm system upon detecting an animal highlights its practical applicability in managing human-wildlife conflict. This outcome is in line with previous studies documented in literature, which emphasize the importance of integrating multi-sensor systems for accurate wildlife monitoring.

Overall, the results indicate that the proposed system is effective in detecting and deterring animals, providing a cost-efficient, scalable, and reliable solution for mitigating human-wildlife conflict. Future enhancements, such as improving sensor range and integrating IoT capabilities for remote monitoring, could further increase the system's utility in diverse environments.

4. Conclusion

The animal detection and deterrence system developed in this study has demonstrated its effectiveness and reliability in addressing human-wildlife conflicts, particularly those involving elephants. By integrating ultrasonic, motion, and thermal sensors with the NodeMCU-ESP32 microcontroller, the system is capable of monitoring designated buffer zones and accurately detecting the presence of animals based on movement, proximity, and heat signatures. The experimental results showed that the system maintained stable operation under normal conditions, with consistent sensor readings, and successfully detected animal intrusions by registering significant changes in sensor data. The activation of the alarm system in response to detected anomalies highlights its practical applicability in real-world scenarios.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Che Muhammad Umair Aiman Che Jemani;* ***solve the governing equation:*** *Che Muhammad Umair Aiman Che Jemani, Afishah Alias;* ***data collection:*** *Che Muhammad Umair Aiman Che Jemani;* ***analysis and interpretation of results:*** *Che Muhammad Umair Aiman Che Jemani, Afishah Alias;* ***draft manuscript preparation:*** *Che Muhammad Umair Aiman Che Jemani, Afishah Alias. All authors reviewed the results and approved the final version of the manuscript.*

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