SMART MONITORING AND REPELLING SYSTEM FOR ELEPHANT INTRUSIONS (HECSENSE)

Project ID- 25-26J-263

Project Proposal Report

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Bachelor of Science(Hons) Degree in Information Technology
Specializing in Information Technology

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DECLARATION

Declaration, copyright statement and the statement of the supervisor

I declare that this is my own work, and this proposal does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or Institute of higher learning and to the best of our knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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The supervisor/s should certify the proposal report with the following declaration.

The above candidates are carrying out research for the undergraduate Dissertation under my supervision.

Signature of the supervisor: [illegible] Date: 26/8/2025

ABSTRACT

In Sri Lanka, human-elephant conflict (HEC) threatens both humans and elephants, causing economic and crop losses. Existing monitoring system mainly use fixed lights or sounds, which elephants quickly get used to, reduce their effectiveness. This project proposes ThreatTrack, a solar-powered, intelligent, eco-friendly system that adapts its response based on elephant behavior, proximity, and time of day.

HECSense modules collect real-time data to map elephant position into safe, warning, and Danger zones and identify their emotional state as calm or aggressive. Pattern-based light and sound sequences, including varying noises and flashing LEDs, prevent habituation, while a rotating system targets deterrents toward approaching elephants. An electric fence can active automatically in emergencies.

A memory module lets the system apply the most effective deterrent based on past encounters. Day/night detection and energy-saving shutdown ensure full solar operation. Multiple devices can be linked via ESP-NOW mesh networking to protect large farms.

ThreatTrack offers a cost-effective, eco-friendly solution to reduce HEC. Compared to fixed-pattern systems, it aims to lower crop loss, reduce human-elephant conflicts, and improve deterrent effectiveness. Integrating adaptive learning, pattern-based deterrents, and renewable energy, the system advanced animal conservation technology.

Keywords: Human-elephant conflict, Adaptive deterrent, Pattern-Based Sound and Light,

Embedded IoT, Solar-powered system

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LIST OF ABBREVIATIONS

Key Words	Meaning
API	Application Programming Interface
EEPROM	Electrically Erasable Programmable Read-Only Memory
ESP32	Espressif System 32-bit Wi-Fi & Bluetooth Microcontroller
ESP-NOW	Espressif Wireless Communication Protocol
HEC	Human-Elephant Conflicts
LED	Light Emitting Diode
RTC	Real-Time Clock
SD	Secure Digital

Table 1 List of Abbreviations

1.0 INTRODUCTION

1.1 Background & Literature Survey

HEC is a significant environmental and agricultural issue in Sri Lanka. Each year, elephants destroy crops, property, and livelihoods of farming communities, and humans retaliate in ways that endanger elephant populations. Sri Lanka has been reporting over 100 human deaths and nearly 400 elephant deaths annually due to HEC encounters, creating ecological as well as economic issues [1], [3], [5].

Traditional techniques such as electric fencing, firecrackers, or manual alarm systems are not effective in the long term. Elephants quickly habituate to repeated deterrents, rendering them ineffective. Moreover, these systems are either costly, ecologically inappropriate, or cannot be scaled for rural farmers [5]. This has led researchers to explore IoT-based, AI-driven, and eco-friendly deterrent systems for safeguarding farmlands while also ensuring the ethical treatment of elephants [2], [6].

Recent approaches combine IoT-enabled detection systems, smart fencing, and automated repellent systems [1], [4], [7]. For example, IoT-enabled laser fences and smart chili deterrent systems have been effective but limited in adaptability and power efficiency [4], [5]. AI-based methods, such as machine learning–enabled intrusion detection and repellent systems, have introduced intelligence into wildlife management [6], [8], but the majority still follow fixed deterrent strategies. These static methods cannot adapt to elephant emotional states, proximity, or repeated encounter, resulting in habituation.

To counter this, ThreatTrack introduces a solar-powered, multi-sensor adaptive deterrent system that combines behavioral, spatial, and environmental data to provide dynamic, real-time, and context-dependent responses. By integrating rotation-based targeting, sound and light pattern switching, memory-based learning, and eco-friendly farmer kits, the system goes beyond conventional static deterrence to provide a scalable and sustainable solution [1], [2], [6], [9].

1.2 Research Gap

Despite significant progress in IoT and AI-powered wildlife deterrent systems, the following are the gaps:

- ✓ Lack of Adaptive Deterrence:

  Most of the current systems employ static sound or light emission, to which the elephants habituate over time. Very few of them embrace pattern-based change to prevent adaptation [6], [8].
- ✓ Limited Integration of Emotion and Distance:

  Systems only detect the presence of elephants but do not combine emotional states (aggressive/calm) and proximity zones (danger, warning, safe) for smarter decision-making [2], [3].
- ✓ Absence of Memory-Based Learning:

  Existing deterrents do not have the capacity to record and recall the results of past encounters. With no learning capability, they cannot employ the optimal response from a past encounter automatically [7].
- ✓ Energy and Sustainability Issues:

  Most of them are power-hungry, utilize grid electricity, or lack auto-shutoff functionality, making them inappropriate for remote rural farms [5], [9].
- ✓ Farmer Usability:

  Available systems are either technically intensive or maintenance-intensive, which discourages low-income rural farmers from using them [1], [5].

These imbalances provide space for an adaptive, scalable, farmer-friendly, and eco-friendly deterrent system that dynamically responds to the behavior of elephants and learns continuously to improve its performance.

1.3 Research Problem

Human-elephant conflict (HEC) has become one of the most critical conservation and socioeconomic challenges in Sri Lanka, threatening both wildlife and human life. Railway accidents kill more than 120 elephants each year, particularly along the Batticaloa, Northern, and Eastern railway lines, and train collisions are one of the leading causes of elephant mortality [10], [11]. At the same time, the severe impact of elephant crop raiding on rural communities is profound, and the agricultural sector suffers great economic damage and hostility towards conservation efforts [12]. Existing approaches to mitigate such impacts are usually non-sustainable and costly to maintain and are incapable of providing an effective prevention mechanism in real time [13], [14].

Technology-based, technology-based solutions for detecting elephants have been described (e. g. seismic sensors, acoustic monitoring and thermal cameras), but they are usually isolated systems, and tend to be disadvantageously biased towards detection by high false positives, lack of directional tracking and inability to integrate with signaling systems in trains. In farming scenarios, eco-friendly and sustainable deterrents such as chili fences and playback of bee sound have been tested but also lack automation and adaptability to elephant behavior [15],[16] Hence, the research problem is the failure of currently-available integrated, intelligent systems that can detect elephants near railway tracks and communicate with train operators, provide adaptive and non-harmful deterrents in farming scenarios while simultaneously supporting long-term monitoring and conservation.

2.0 OBJECTIVES

2.1 Main Objectives

This project intends to improve human and elephant safety in Sri Lanka by putting in place a multi-modal elephant detection and deterrence system within a year. To accurately identify elephants near farmlands and railroad tracks, the system will combine computer vision, walking vibration sensing, and acoustic analysis. The system aims for at least 90% detection accuracy by utilizing these complementary sensing techniques. By reducing the likelihood of train-elephant collisions by half and crop damage caused by elephants by half, its implementation is anticipated to result in a net 10% decrease in total crop loss. Field tests and community cooperation in designated high-risk areas will be used to assess these quantifiable results. The goal is time-bound because the one-year period guarantees prompt research, design, development, and pilot implementation. All things considered, this objective is clear, quantifiable, doable, pertinent, and time-bound; it directly addresses a significant socio-environmental issue and promotes sustainable coexistence between humans and elephants.

2.2 Specific Objectives

The following detailed goals will be addressed to achieve the general goal:

1. Create Zone-Based Adaptive Logic

   ✓ Implement Safe, Warning, and Danger zones to adjust deterrent intensity based on elephant distance and direction.

2. Incorporate Emotion-Aware Responses

   ✓ Correlate elephant emotional states (calm/aggressive) with the matching deterrents to eliminate unnecessary stress and optimize effectiveness.

3. Create Rotating Deterrent Mechanism

   ✓ Utilize servo motors to rotate deterrent units towards the elephant for targeted effect and improved energy efficiency.

4. Implement Pattern-Based Sound and Light Deterrents

   ✓ Generate random predator calls, buzzing bees, and changing LED flash patterns to prevent habituation to repeating patterns.

5. Provide Memory and Learning Capability

   ✓ Store historical deterrent outcomes in EEPROM/SD memory and automatically use the best method with every subsequent encounter.

6. Offer Energy Efficiency and Eco-Friendliness

   ✓ Power the whole system through solar energy, provide auto day/night detection, and implement automatic power-off upon elephants' exit.

7. Provide Modular Farmer Kits

✓ Develop add-on deterrent modules such as chili mist sprayers, LED fences, and sound equipment that are inexpensive, scalable, and easy to use to rural farmers.

8. Develop ESP-NOW Wireless Networking

✓ Mesh network several deterrent units using mesh communication to expand protection over large farmland dimensions and coordinate multi-zone defense.

3.0 METHODOLOGY

The method of this research was to develop a structured framework which will combine railway safety mechanisms with farm-oriented monitoring and deterrent systems to produce a coherent system. Its overall structure is modular and interconnected. Therefore, each subsystem can work autonomously but also contributes to achieving the overall aim, namely minimizing the chances of human-elephant interaction. For railway areas a layered sensor network will be deployed along identified high risk track segments. Geophones will be used to detect seismic vibrations caused by the elephant's footsteps, and directional microphones will capture low-frequency elephant calls and movements sounds. The collected data will be processed at edge computing units which are trained on digital filtering, feature extraction, and machine learning classification to make accurate distinctions between elephants from trains, vehicles or disturbances in the environment. By studying sequential sensor activations at 10m, 6m, 3m and 1m intervals the system can infer the presence and direction of elephants and enable early warnings and risk assessment.

Once the elephants are detected by the sensor or on the track, there are two layers of response: Deterrent measures may be carried out (in the first stage non-destructive deterrents) to prevent another elephant from approaching, such as flashing strobe lights, loud alarm or playback of a distress call. If deterrents do not work and the risk worsens, the system communicates directly with the railway control network via GSM or LoRa-enabled channels. The train operator is then notified, or in very severe situations, an automated braking mechanism is activated to prevent the elephant from colliding with the train.

The methodology is also equipped to work with farmland to reduce collisions between elephants and crops - also known as crop-raising. Smart collars with physiological sensors will be worn on the elephants in defined high-conflict areas. The physiological monitoring data will reveal important details about stress, aggression and health; extra information about herd movements can also be collected with help from camera-based behavior analysis. Comparatively with the collar and farm-based monitor units, information on each elephant's activity is continuously transmitted to a central database. Based on the information gathered from the collars and farm monitoring units, sustainable deterrent units will be activated at farm sites, such as chili sprays, bee-sound playback and high intensity lights. The deterrent units will be chosen adaptively based on behaviors of the animals in question and their proximity.

In order to ensure system reliability and sustainability all field devices will be powered by solar energy and provided with a battery backup, which will allow them to operate continuously around the clock, in remote rural districts. A centralized cloud-based monitoring and analytics platform will bring together data from both the railway and farming domains and provide real-time dashboards, hotspot mapping and analytics to the railway authorities, farmers and wildlife officers, thus ensuring both rapid, automated intervention as well as long-term conservation planning by providing timely insights to elephant movement and conflict dynamics.

3.1 Complete System Architecture

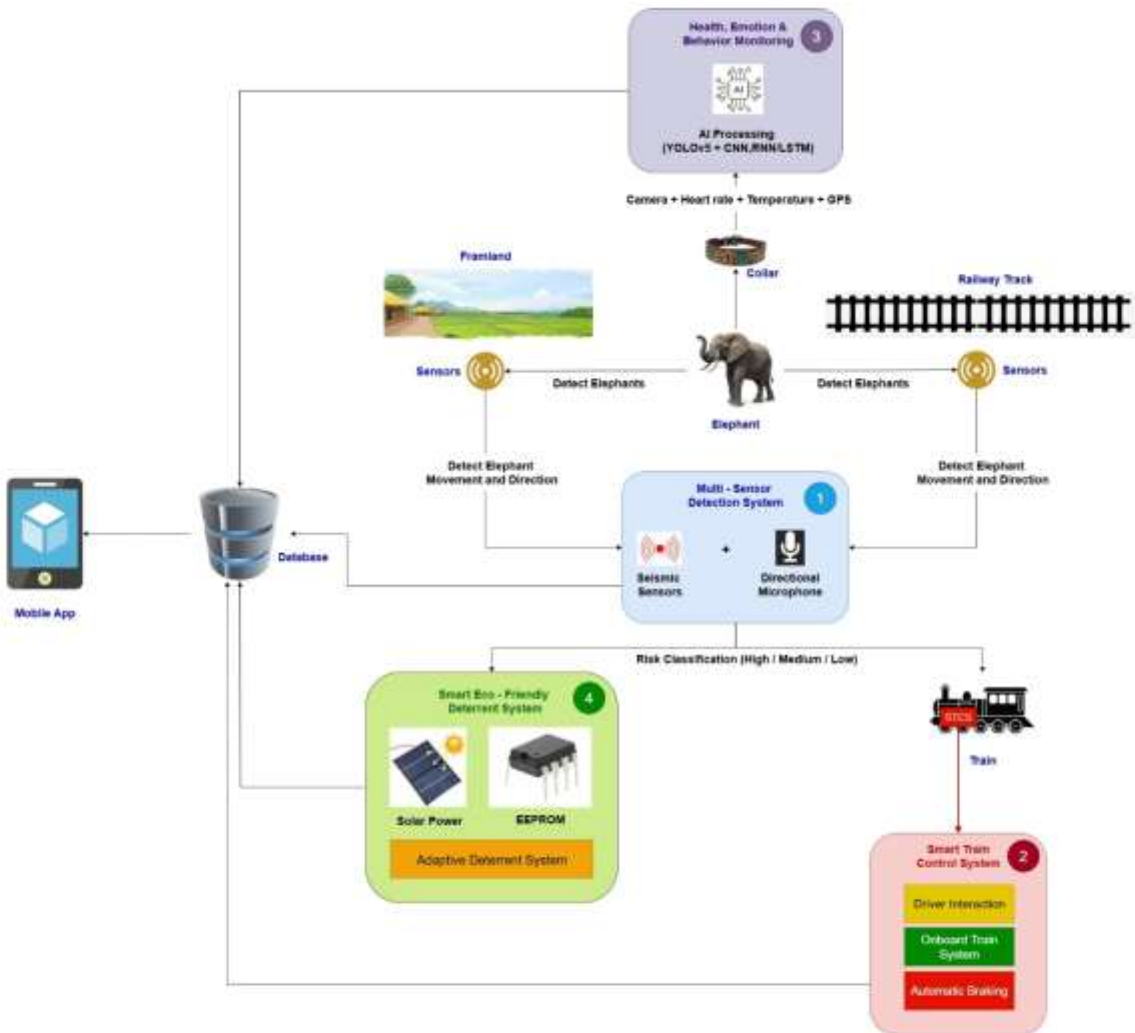

Figure 1 Complete System Architecture

3.2 Component Architecture

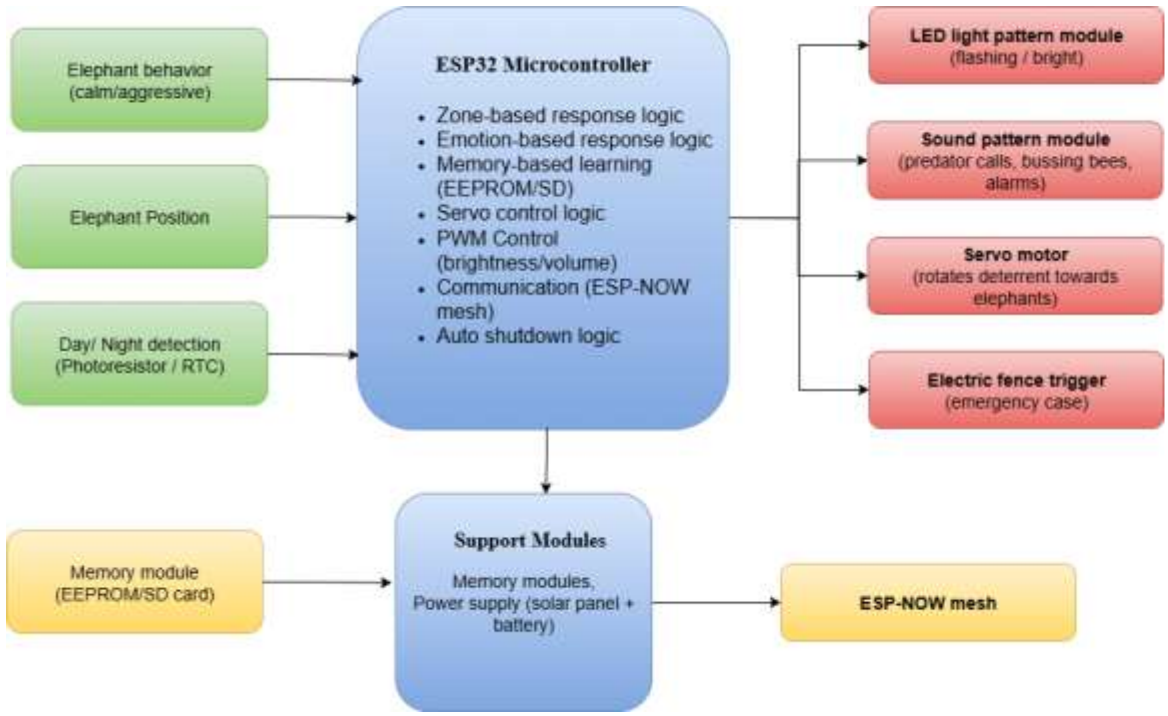

Figure 2 Component Architecture

4.0 PROJECT REQUIREMENTS

4.1 Functional Requirements

1. Zone Based Deterrence

   - ✓ Safe zone - System on standby mode to minimize power usage.
   - ✓ Warning Zone - light starts flashing and low level sound patterns are triggered.
   - ✓ Danger Zone - high frequency sound patterns, light flashing, chili misting and electric fencing are operated.

2. Emotion Based Response - Change the level of the deterrent based on whether the elephant is calm or acting aggressively.
3. Rotating Targeting Method - Servomechanism controlled rotation to maximize deterrent effect.
4. Pattern Based Sound and Light - Alternative predator calls, buzzing insect sounds and random LED flashing to avoid habituation from the elephants.
5. Memory and Learning Module - Tracks effectiveness of deterrent and automatically redeploys effective method pattern on similar confrontations.
6. Energy savings/auto shutdown - Automatically detects day/night and shuts down when elephant exit.
7. Wireless Mesh Network - Coordinated multiple device working over wide areas of farmland.

4.2 Non-Functional Requirements

1. Reliability – Guarantee consistent uptime of the system with very few false activations.
2. Scalability – Enable many units to be deployed and coordinated over a large area.
3. Eco-Friendliness – Operate on solar power and use natural deterrents (bee sounds, chili mist).
4. Farmer Usability – Modular farmer kits that are simple, affordable, and low maintenance.
5. Safety & ethics – No physical harm to elephant; make sure deterrents do not harm animals in a lethal way.

4.3 Expected Test Cases

1. Unit Testing: All parts of ThreatTrack will be initially tested separately, ensuring that they perform as intended.

• Sound and Light Module: Determine if randomized patterns of sound (predator calls, bee buzzing) and LED light patterns operate correctly. Also, evaluate if the sequences differ to decrease habituation.

• Servo Motor and Directional Viewing Module: Evaluate the servo responding to a simulated array of elephant approach data for correct directional rotation towards the target.

• Electric Fence Trigger Module: Test relay activation independently to confirm the fence is turned on only in the Danger zone.

• Memory Module: Determine if deterrent effectiveness is correctly logged (e.g. sound success versus success of light) and recalled in later encounters.

2. Integration Testing: Modules will be combined to test their interactions.

• Combine the Zone Detection Module with the Sound & Light Module to validate that deterrents activate appropriately when elephants enter and subsequently leave Safe → Warning → Danger zones.

• Test the Memory Module with Deterrent Activation to make sure that the system uses the most recently effective deterrent in the same situation.

• Check that the solar power input integrates appropriately with day/night detection and auto-shut-off features.

3. System Testing: The entire ThreatTrack system will be evaluated under both the simulated and natural setting.

• Zone-based Testing: Confirm that different types of deterrent responses are triggered when elephants enter Safe, Warning, and Danger zones.

• Adaptive Behavior Testing: Simulate capture of the elephant over repeated approaches, to verify that the program not only avoids repeated responses but then changes the order of the deterrent responses.

• Fail-Safe Testing: Confirm the electric fence, if activated only when it should be and that the system can undergo a safe power down if no threat has been detected.

• Scalability Testing: Operate multiple units utilizing ESP-NOW mesh networking to confirm the communications remain stable over wide farmland area.

• Sustainability Testing: Ensure it continuously operates on solar power alone, including a power saving shut down when light conditions get low.

System testing will confirm that ThreatTrack operates as a reliable, adaptive, environmentally friendly deterrent system for Human - Elephant conflict mitigation.

4.4 User Requirements

The main end-users of the ThreatTrack system are farmers, wildlife officers (wildlife and park rangers), and communities who are directly affected by HEC. The ThreatTrack system should be designed to meet the following User-Centered design criteria:

Ease of Use: Farmers with low or no technical skills, should be able to operate the systems with minimal training, Simple on/off control and visual status indicators (LEDs).

Affordability: The system must be low-cost and affordable for rural peoples with limited financial means.

Reliability: The deterrent system should successfully work at night, in bad weather, and under variable farmland conditions.

Non- Harmful Operation: The system should deter elephants and not physically harm them to ensure safety for humans and wildlife.

Maintenance Friendly: The components (solar panel, battery, sensor) should be replaceable or repairable locally, with ease of use.

Scalability: Users should be able to extend their protection capabilities by linking several deterrent units together to cover larger farmland areas.

4.5 System Requirements

Zone Classification and Context Awareness: The system shall categorize farmlands into Safe, Warning, and Danger zones via proximity detection of the elephant. The deterrent response is then initiated based on elephant movement and zone classification.

Adaptive Deterrent Selection: The system shall adaptively select sound/light patterns or activation of an electric fence based on elephant movement and past experiences of deterrent outcomes. The aim is to minimize habituation.

Rotating Mechanism Control: The system shall automatically rotate deterrent units (speakers and lights) based on the elephant's location through a servo-driven rotation to target the approaching elephant for achieving deterrent efforts.

Memory-Enabled Learning Module: The system shall record the effectiveness of each deterrent method from each encounter and ranking the best methods to preferentially be used in future encounters.

Minimal Latency Activation: Deterrent initiation (sound/light/fence) must occur within 1–2 seconds of approaching elephants to ensure a more influential real-time response.

Uptime and Fail-Safe Availability: The system should remain above >95% uptime, and must have capabilities to fail-safe operating in partial sensor and/or actuator failure**.**

Solar-Powered and Energy Efficient: The system should operate completely on solar energy - rechargeable batteries for electric storage, and capable of auto day/night detection and auto shut off function when no threats are present.

Multi-Unit Communication: Architectural stacks must include ESP-NOW multi-device mesh networking to allow shared elephant movement data across a wide areas of farmland to allow coordinated deterrent.

Environmental Sustainability: Deterrent methods must remain non-lethal to elephants, and humans must remain safe from threat, ensuring adherence to wildlife conservation strategies.

Durability and Weather Resistance: All physical components must also be weather-tight weather for operation in challenging outdoor environments (rain, dust, heat).

4.6 Ghant Chart

Figure 3 Ghant Chart

4.7 Work Breakdown Structure

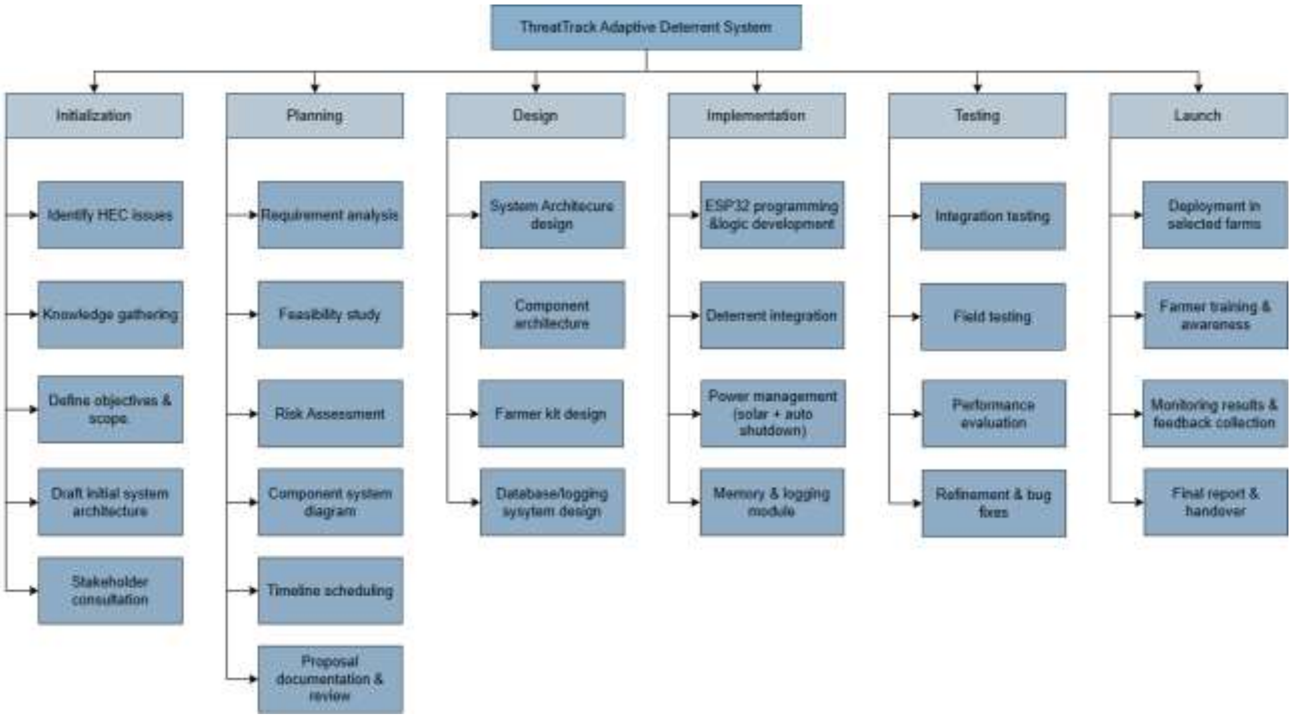

Figure 4 Work Breakdown Structure

5.0 BUDGET AND BUDGET JUSTIFICATION

Item	Description	Cost Estimation
Microcontroller(ESP32)	Primary control for modules, exercises, and communication to the database.	$12(one-time)
Sensors & Actuators	Photo resistor, RTC,servo,RGB LEDs, mic & speaker for user interaction	$35 (one-time)
Data Storage	Local storage of performance logs, memory-based learning history, and user interactions.	$7 (one-time)
Power Supply	Provides continuous use offline; portable, low-cost	$15 (one-time)
Solar Panel	Small panel for sustainable uses in rural/low-power environments.	$18 (one-time)
Miscellaneous (Wires,PCB,Casing,Connectors)	Includes essential accessories and protective housing.	$20 (one-time)

Table 2 Budget and Justification

Estimated Total Cost: ~ $107 (one-time)

1. Microcontroller (ESP32) - Selecting ESP32 Microcontroller for its low cost, on-board WI-FI/Bluetooth and ability to manage every module of the system.
2. Sensors & Actuators - Provides the interaction system which includes detecting context, playing adaptive audio-visual cues, and letting the users act for interaction.
3. Data storage - Using local data storage is cost friendly compared to using the cloud and can help manage the memory-based learning aspect of features.
4. Power Supply - The indicator for a rechargeable battery system provides continual operation at a low cost.
5. Solar Panel - Supports eco-friendly design, reduced power consumption and supports sustainability projects.
6. Miscellaneous - Support costs for wiring, Connectors and protective case to ensure a robust prototype.

6.0 CONCLUSION

The primary objective of this research is to design and implement ThreatTrack, an adaptive deterrent system powered by solar energy with the aim of reducing Human–Elephant Conflict (HEC) in Sri Lanka. In contrast to traditional deterrence methods that use static light or sound, ThreatTrack offers pattern-based deterrence, zone-based adaptive reasoning, emotion-responsive outputs, and memory-driven learning to avoid habituation of elephants to repeated stimuli.

The system is completely integrated with the entire HECSense system, with live feed inputs of elephant closeness and emotional state employed in selecting and activating the best-suited deterrents dynamically. By combining servo motor rotation for directional aim, randomized light and sound sequences, and intelligent energy management, ThreatTrack realizes both effectiveness and sustainability.

This research is motivated by the pressing need for cost-effective, environmentally sustainable, and farmer-friendly deterrent systems that can be practical in rural, resource-limited settings. The proposed solution closes this gap by leveraging renewable power, low-power IoT technology, and simple-to-deploy and service modular farmer kits.

In summary, ThreatTrack provides an innovative and scalable solution to HEC mitigation. By blending adaptive technologies, behavioral intelligence, and renewable energy, the system offers a humane, effective, and eco-friendly alternative to traditional deterrent methods. Its successful implementation has the potential to reduce crop loss, improve farmer welfare, and facilitate peaceful human–elephant coexistence with wildlife conservation initiatives in Sri Lanka.

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APPENDICES

- Technology Stack
  - ✓ Programming Language – Arduino C++ (for ESP32 control logic , basic sensor control , and deterrent pattern execution)
  - ✓ Microcontroller – ESP32 (inexpensive WI-FI enabled microcontroller for system control and communication)
  - ✓ Database / Storage – EEPROM / SD Card (for logging deterrent effectiveness and memory-based learning)
  - ✓ Pattern-Based Logic – Zone-based state machine (Safe, warning, Danger) with randomized Light & Sound Patterns.