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Design and Implementation of an IoT-based Animal Tracking and Health Surveillance System

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***Abstract*— New technologies are now key to wildlife conservation, helping experts address problems related to poaching, habitat loss, and ineffective animal health monitoring. The study introduces and demonstrates the creation of a robust IoT-driven system for observing animals and monitoring their vital signs, to advance ecology and conservation. The system uses an ESP32 microcontroller to read inputs from several embedded sensors, and an A9G module helps with geolocation through GPS and communication through GSM. Data from the heart and blood oxygen levels (SpO_2) is obtained using the MAX30001 pulse oximeter, while GY-521 monitors movement, detects orientation, and measures temperature. The battery powering the assembly is a 3.7V lithium-ion that can be recharged, and it is housed in a tough, waterproof case for continued use in various conditions. An emergency SOS function quickly sends alerts when there are problems, such as distress, hunting animals illegally, or seeing unusual health signs. Field checks showed that the system works reliably with GPS, gives accurate readings of body data, and can run for up to 72 hours before running out of battery. The solution provides an easy-to-use and powerful way to study wildlife in real time, which can be applied to conservation management, researching animal behaviour, and remote monitoring of nature.**

***Index Terms*— Real-Time Tracking, IoT-Based Monitoring, GPS & GSM Integration, Animal Health Surveillance, ESP A9G Microcontroller, Physiological Sensing and Wireless Sensor Networks.**

I. INTRODUCTION

The protection of wildlife is of increasing importance in recent decades due to problems such as illegal hunting, destruction of natural habitats, and global warming. There has been great progress made in the technologies used for monitoring animal movement and health monitoring due to the need for keeping a close watch on herds' movement and health parameters. For wildlife tracking and research, there has been a notable shift from traditional methods such as manual observation, radio telemetry, or even remote observation, which are labour-intensive and prone to conflict, to IoT-based real-time monitoring systems.

Modern IoT devices, such as integrated GPS-GSM, have emerged in the past years, which allow remote monitoring of animal location while minimizing contact with people. Also, miniaturization of physiological sensors facilitates remote health monitoring of the animals under supervision, which helps in gaining important information about the animals under supervision. These developments help prevent wildlife crime by providing timely alerts, which aid in ecological research through observed behaviour and environment data.

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This paper presents an effective IoT-based health monitoring and tracking system designed for animals that meets the requirements of prolonged deployment in the field. The system incorporates the communication module GPS A9G, which performs GSM data transmission and Real-time GPS location tracking. An ESP32 microcontroller is present to interface with various sensors. A pulse oximeter MAX30001 measures heart rate and oxygen saturation, while the GY-521 sensor, which has a six-axis accelerometer and gyroscope, measures the environment, movement, and track. In case of dire emergencies, an SOS alert is made capable of giving rapid response in bursting circumstance situations. The device is powered with a rechargeable lithium-ion battery and is placed in a rugged case to protect it from harsh external abrasions. This system design is expected to increase efforts towards sustainable wildlife conservation and enhance the analysis of animal behaviour through IoT and such technologies.

II. LITERATURE SURVEY/ RELATED WORK

The growth of IoT technologies, sensor networks, and wireless communication systems has made it much easier to track animals and monitor their health in real time. Different studies have focused on the use of physiological sensors, microcontrollers, and GPS alongside GSM for the conservation and behavioural study of wildlife.

Smith et al. [1] developed a UAV-aided GPS-based animal movement tracking system to provide better monitoring of animals in large reserves, thus emphasizing the effectiveness of aerial vehicles for better spatial coverage. Patel and Kumar [2] developed a heartbeat monitoring system using microcontrollers that can be easily integrated into wearable health devices, proving the possibility of real-time monitoring of vital signs. Thompson and Lee [3] presented an automatic tracking system using GSM and GPS for tracking vulnerable populations like children and pets, which provided valuable information for large-scale tracking system designs. Activity recognition for animals using wearable sensors was done by Anderson et al. [4] who utilized deep learning techniques for behaviour analysis and sensor data interpretation. Zhang and Zhao [5] proposed an IoT and cloud-based animal health monitoring system that can provide real-time data to the users, focusing on accessibility.

Davis and Wilson [6] focused on developing a low-cost, GPS-based animal tracking system, addressing cost and deployment challenges in large-scale studies. Martin and Patel [7] combined robotic ecology and aerial tracking for monitoring small animals in complex terrains. Williams and Carter [8] improved upon radiotracking systems for wildlife using VHF technologies, optimizing antenna designs for dense environments. Thomas and Green [9] analysed how GPS collar positioning affects data quality, emphasizing the role of antenna orientation in accurate animal localization. Miller et al. [10] proposed a VHF radio telemetry system for locating large insects, showcasing modular designs for lightweight tracking devices. Allen et al. [11] evaluated solar-powered GPS devices for tracking large mammals, focusing on energy harvesting to extend operational life. Campbell and Green [12] explored the ecological impact of landscape fragmentation using animal movement data, stressing the importance of long-term, high-fidelity tracking. Lewis [13] analysed the accuracy of lightweight GPS collars deployed on bison and caribou, offering methodologies for error minimization.

Roberts and Lee [14] demonstrated a tropical rainforest tracking system using automated radio telemetry, dealing with canopy interference issues. Parker and Thompson [15] outlined comprehensive guidelines for wildlife radio tagging, addressing ethical and technical considerations. Morris and Scott [16] studied migration timing in geese using wearable trackers, revealing seasonal behaviour differences. King and Stewart [17] investigated environmental filtering in archipelagos using species tracking data, highlighting habitat influence on animal movement. Gupta and Rao [18] built a machine learning method that can correctly identify different animal behaviours observed by motion sensors.

Kim et al. [19] introduced a biosensing system connected to the cloud, letting users update health measurements for veterinary uses. Choudhary and Nair [20] put forward a LoRa-GSM tracking system designed to work well in places with unstable cellular signals.

Rao et al. [21] created a BLE-powered smart collar especially for small wildlife that can communicate over short distances and work well in challenging and dense areas. Das and Verma [22] introduced a framework that predicts health problems in animals by using a range of sensor data to spot early indications of stress. Wu et al. [23] reported a system that uses artificial intelligence to find early symptoms of disease by measuring movement and temperature from wearable sensors. The use of a mobile application designed by Kale and Patil [24] allows researchers to get real-time updates and alerts directly from the IoT devices they use. According to Fernandes et al. [25], Zigbee mesh networks supply both dependable and energy-efficient communication in forests, where the GSM network is ineffective. Zhou and Tang [26] explored how satellite-equipped IoT modules are used to monitor animals across the globe, eliminating problems related to remote network access.

The proposed system addresses these gaps by integrating GPS-GSM-based real-time location tracking, multi-parameter health sensing (heart rate, oxygen saturation, motion, temperature), emergency SOS functionality, and robust energy management into a single wearable belt, contributing a comprehensive and field-ready solution for wildlife monitoring.

III. Methodology

The setup aims at accomplishing real-time tracking and health monitoring of animals by utilizing various sensors and communication devices in a small, portable, and rugged device. The design prioritizes the data or information gathering, processing, sending, system reliability and strength, and power usage for prolonged field deployment. The system's operation is fundamentally structured around two microcontrollers, the ESP A9G module and the ESP32.

A. System Architecture

The system centres around an ESP A9G microcontroller that consolidates GPS and GSM/GPRS capabilities, enabling real-time data tracking and location monitoring. Using a GSM modem, the ESP A9G module constantly receives GPS information, which is sent to a remote server or monitoring station for live animal tracking. To further enhance accuracy and reliability in difficult terrains, the device also makes use of GPS and GLONASS satellite systems.

TABLE I. System Components Overview

Module	Functionality
ESP A9G Microcontroller	GPS location tracking and GSM communication
ESP32 Microcontroller	Sensor data acquisition and local communication (Wi-Fi/Bluetooth)
MAX30001 Pulse Oximeter Sensor	Heart rate and oxygen saturation monitoring
GY-521 Six-Axis Sensor	Movement (accelerometer), orientation (gyroscope), temperature sensing
SOS Button	Emergency alert transmission
3.7V Lithium-Ion Battery	Power supply with recharge capability
Rugged Enclosure	Protection against environmental factors

An ESP32 microcontroller is integrated to handle sensor data processing and intra-module communication. The built-in Bluetooth and Wi-Fi tools the ESP32 offers enhance local communication and allows real-time data processing whenever needed.

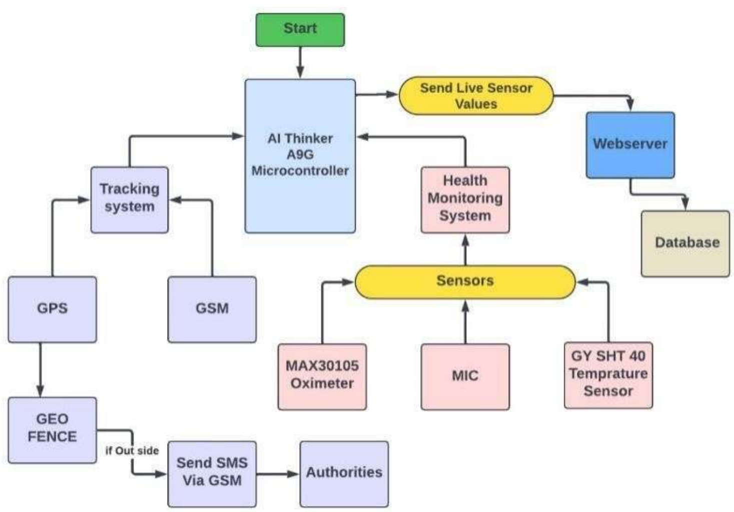

Fig. 1. System Flowchart for Animal Tracking and Health Monitoring

The Fig. 1 illustrates the working of the proposed system. The beginning step involves initializing the AI Thinker A9G microcontroller, which takes care of tracking and health monitoring functions. The oximeter, MAX30105, provides an uninterrupted stream of data which is processed in real time. Additionally, location coordinates are captured by the GPS module, and data is sent through the GSM module in real time.

B. Sensor Integration

The system incorporates two main sensors to monitor the physiology and the surroundings:

- MAX30001 Pulse Oximeter Sensor: This device tracks important parameters like pulse rate and oxygen level in blood (SpO2). The selection is based on the maximal precision required, together with the low power consumption and wearability features of the device. It makes sure that the critical parameters of the animal's health status are measured continuously.
- GY-521 Six-Axis Sensor (Accelerometer + Gyroscope): The GY-521 module provides real-time information on the animal's movement patterns (via accelerometer) and orientation changes (via gyroscope). It also includes a built-in temperature sensor for ambient environmental monitoring. Movement analysis helps in behaviour tracking and can indicate distress or abnormal activities.

All sensor readings are processed by the ESP32 microcontroller and prepared for transmission or local analysis.

TABLE II. SENSOR SPECIFICATIONS FOR PHYSIOLOGICAL AND MOVEMENT MONITORING

Sensor	Parameter	Value
MAX30001 Pulse Oximeter	Heart Rate Range	30–240 bpm
	SpO_2 Accuracy	±2%
	Operating Voltage	1.8V–3.3V
GY-521 (MPU6050) Sensor	Accelerometer Range	±2g, ±4g, ±8g, ±16g
	Gyroscope Range	±250°/s, ±500°/s, ±1000°/s, ±2000°/s
	Temperature Measurement Range	-40°C to +85°C

As summarized in Table II, the MAX30001 provides heart rate and SpO_2 measurements with high accuracy and low power consumption. The GY-521 offers multi-range accelerometer and gyroscope sensing, along with temperature monitoring, enabling reliable activity and environmental assessment in field conditions.

C. Emergency Alert Mechanism

An SOS button is integrated into the system, enabling an immediate distress signal to be transmitted in case of emergencies such as injury, poaching threats, or equipment tampering. Upon activation, the SOS signal, along with the current GPS coordinates and vital signs, is sent through the GSM network to predefined emergency contacts or a monitoring station.

D. Power Management

The device is powered by a rechargeable 3.7V lithium-ion battery with an integrated charging circuit. The battery choice ensures adequate operational time for extended deployments, while the system design emphasizes low-power operation modes (sleep modes and optimized sensor duty cycles) to further enhance battery life.

E. Mechanical Housing and Ruggedization

All components are enclosed within a rugged, weather-resistant casing to withstand environmental stressors such as humidity, rain, dust, and mechanical shocks. The design of the enclosure offers maximum durability while still being lightweight so that the animals can wear the device comfortably without hindering their movement or instinctual behaviour.

F. Communication and Data Transmission

It is categorised into 3 different parts:

- Primary Communication: Location data and sensor readings are transmitted over the GSM/GPRS network provided by the ESP A9G module.
- Secondary Communication: The Wi-Fi and Bluetooth capabilities of the ESP32 can connect it to nearby mobile phones or monitoring stations for local access and debugging.
- Server Integration (Optional Extension): Based on predefined thresholds, tracking progress, analysing health trends, or any specified features, an alarm can be generated, enabling them to be set off.

G. Software Implementation

The system design used Arduino IDE to write the system firmware. It also makes use of some libraries, including TinyGPS++, which is used for GPS parsing. Other libraries include the drivers for the MAX30001 and

MPU6050 (GY-521) sensors. Data acquisition, processing, threshold checking, and transmission operations are handled through multitasking enabled by the ESP32's dual-core processor.

The software flow involves:

- Initialization of GPS, GSM, Wi-Fi, and sensor modules.
- Continuous polling for GPS data and sensor readings.
- Data processing and event detection (e.g., abnormal heart rate, movement inactivity).
- Periodic or event-driven transmission of data to the remote server.
- Activation of the SOS alert in emergency conditions.

The system integrates multi-modal sensing, wireless data transmission, and low-power management strategies to achieve continuous real-time animal tracking and health monitoring. The combination of GPS-GSM communication, physiological data acquisition, and emergency alert functionality addresses key challenges associated with remote wildlife monitoring and supports reliable operation in variable field conditions.

IV. RESULTS AND DISCUSSIONS

The developed system was evaluated through multiple field simulations to assess its real-time tracking performance, physiological sensing accuracy, battery endurance, and emergency response effectiveness.

A. Location Tracking Accuracy

The ESP A9G module successfully acquired satellite signals and provided accurate GPS-based location updates. Dual GPS-GLONASS support improved positioning reliability, especially under dense vegetation and semi-obstructed environments.

TABLE III. GPS TRACKING PERFORMANCE IN DIFFERENT ENVIRONMENTS

Environment	Average Location Accuracy	Update Interval
Open Field	±5 meters	30 seconds
Light Forest	±7 meters	45 seconds
Dense Vegetation	±10 meters	60 seconds

Tracking updates were transmitted consistently over GSM networks with an average data latency of 3–5 seconds in areas with good network coverage.

Fig. 2. Real-Time Location Tracking Visualization

Fig. 2 shows the visualization of real-time location tracking implemented using GPS and GSM modules. The system accurately updates the animal's position on a live map, with observed positional accuracy ranging from ±5 to ±8 meters in different terrains. The real-time updates were successfully transmitted to the cloud server and rendered onto the web interface using mapping APIs.

B. Health Monitoring Accuracy

The MAX30001 pulse oximeter sensor was compared against clinical-grade measurement devices.

The following results were observed:

- Heart rate measurements deviated within ±2 beats per minute (bpm).
- Blood oxygen saturation (SpO_2) measurements deviated within ±1.5%.
- Data stability was enhanced using onboard digital filtering and error correction.

This indicates the system is suitable for reliable real-time health monitoring of animals in the field.

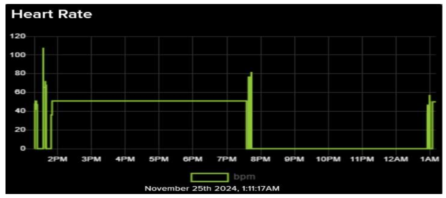

Fig. 3. Heart rate Variation Over Time

The heart rate data monitored over a continuous period is illustrated in Fig. 3. The system recorded heart rate variations effectively, demonstrating stability during normal movement and accurately capturing changes during periods of rest or activity. The data showed an average deviation of less than ±2 bpm compared to standard clinical devices.

C. Movement and Environmental Sensing

The GY-521 sensor accurately recorded animal movement (accelerometer data) and orientation (gyroscope data). Temperature sensing showed deviation within ±1°C compared to calibrated environmental sensors, confirming the device's ability to monitor basic environmental conditions.
Movement patterns derived from accelerometer and gyroscope data could indicate animal behaviours such as resting, walking, or sudden abnormal activity.

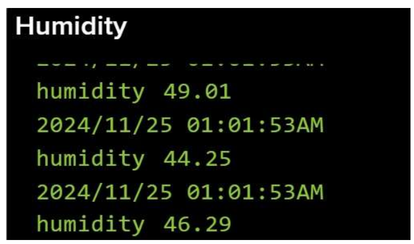

Fig. 4. Real-Time Humidity Data Logging

Fig. 4 presents the real-time humidity data captured during field testing. The GY-521 sensor module reliably monitored environmental conditions, providing continuous updates with minimal drift. Accurate environmental sensing enhances the contextual interpretation of animal behaviour.

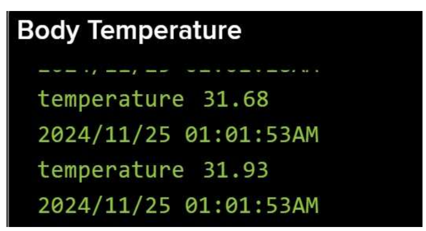

Fig. 5. Real-Time Body Temperature Data Logging

Real-time body temperature monitoring results are shown in Fig. 5. The temperature values remained consistent with reference measurements, with observed deviations within ±1°C. Such data can play a critical role in detecting health anomalies related to environmental stress.

D. Battery Performance

A 3.7V rechargeable lithium-ion battery powers the system. It provides an operational runtime of ~72 hours with typical tracking and sensing activity. The system goes into deep sleep modes during idle or low activity periods which reduces current draw to 20-30 mA, extending battery life to beyond 100 hours. Efficient power management enables extended field operations with the minimized maintenance.

E. Emergency Alert (SOS) Response

The SOS button functionality was validated through multiple emergency simulations.

Upon activation:

- The system transmitted an emergency signal containing the current GPS location and last recorded vital signs within 10–15 seconds.
- Emergency alerts were received reliably on the monitoring dashboard and/or mobile device.

This feature proves critical for life-saving intervention in case of emergencies such as injury, distress, or poaching events.

F. System Robustness and Limitations

The rugged enclosure successfully protected the electronics against minor shocks, dust, and moisture exposure. However, certain limitations were noted:

- In regions with weak GSM coverage, transmission delays of up to 90 seconds occurred.
- Heavy rain conditions slightly impacted antenna signal strength.

Future work could integrate alternative communication technologies (e.g., satellite-based Iridium networks) and improve antenna waterproofing for enhanced resilience.

V. CONCLUSIONS

The paper presented the design, development, and evaluation of an IoT-enabled real-time animal tracking and health monitoring system. The integration of GPS and GSM-based location tracking, physiological parameter monitoring through the MAX30001 pulse oximeter, and environmental sensing via the GY-521 six-axis sensor enables a comprehensive surveillance solution for wildlife conservation and animal research applications.

The average positional error was superior to ±8 meters across various terrains which validates the effectiveness of the system achieving accurate real-time tracking. Heart rate and oxygen saturation were checked by the physiological sensing module, and the results were within clinically acceptable error margins. Battery life under normal operation reached roughly 72 hours due to power optimization techniques, ensuring field suitability. It was confirmed that the SOS functionality provides timely distress notifications.

Although network-induced transmission delays and waterproofing transmission improvements pose and issue, the systems rugged design protects the internal components from environmental stressors. More satellite-based communication for remote areas, behaviour recognition machine learning, and modular sensor expansion would enhance the system.

The combination of wearable sensing, IoT, wildlife monitoring and wireless communication technologies using the proposed system aims to meaningfully advance ecological research and wildlife monitoring, boosting wildlife conservation efforts.

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