An extensible AI and RFID System for Wildlife Tracking and Health Monitoring

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Declaration

We appreciate the almighty God who has given us life since the time we were born and also granting us opportunity to study and excel in our academics since our education started. Secondly, we take this chance to also appreciate our Dads, mothers, brothers and sisters for the care they have shown us upon our academics. in bold, we thank our supervisor Mr. Tonny Engwau who has surely helped us upon every thing in our academics

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Chapter 1

Introduction

1.1 Introduction

The conservation of endangered species, such as the mountain gorillas of Bwindi Impenetrable National Park, is a pressing global concern due to their critical ecological role and vulnerability to extinction [1].Traditional monitoring methods, which rely heavily on human observation, are labor-intensive, inconsistent, and risk transmitting diseases from humans to gorillas, posing significant threats to their survival[2].The integration of advanced technologies, including the Internet of Things (IoT), Artificial Intelligence (AI), and Radio Frequency Identification (RFID), presents a transformative opportunity to overcome these challenges by enabling real-time, non-invasive tracking and health monitoring [3]. technologies facilitate early detection of health issues, enhance understanding of behavioral and reproductive patterns, and support data-driven conservation strategies, thereby improving outcomes for endangered species [4]. The limitations of current monitoring approaches and proposed the development of an AI and RFID-based Wildlife Tracking and Health Monitoring System to address these gaps. There is relevant literature, confirming the potential of IoT, AI, and RFID in wildlife monitoring but identifying a critical research gap in their integrated application for comprehensive health and tracking systems, particularly for mountain gorillas. Building on these foundations, there is outline of a systematic methodology employing a Design Science Research (DSR) approach to design, simulate, and evaluate an integrated system tailored to the conservation needs of wild animals especially the mountain gorillas in Bwindi Impenetrable National Park[5]. The methodology encompasses the generation of simulated IoT sensor data, development of AI models for health and behavioral analysis, integration of RFID for precise tracking, and creation of a user-friendly dashboard to provide actionable insights for conservationists.

1.2 Background

Globally, wildlife populations are increasingly threatened by extinction, necessitating innovative and effective conservation strategies to protect biodiversity.

In Africa, iconic species play critical roles in maintaining ecological balance and supporting tourism-driven economies. The mountain gorilla, particularly in East Africa, exemplifies the urgent need for advanced conservation tools due to its endangered status and ecological significance. While this study initially focuses on mountain gorillas in Uganda's Bwindi Impenetrable National Park, which hosts nearly half of the world's remaining mountain gorilla population, the proposed system is designed to be extensible to other wildlife species across diverse habitats.[6]. Bwindi's dense, rugged forests pose significant challenges for traditional monitoring methods, which rely on labor-intensive human observation. These methods are intermittent, resource-heavy, and carry risks of disease transmission from humans to animals, threatening the health of vulnerable populations like mountain gorillas [7]. To address these limitations, modern technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Radio Frequency Identification (RFID) offer transformative solutions for wildlife monitoring. Smart collars equipped with IoT sensors can continuously collect vital health data, such as heart rate, body temperature, and activity levels, while RFID tags enable precise tracking of individual animals' movements. AI algorithms can analyze this data to detect early indicators of illness, stress, reproductive states, or behavioral anomalies, enabling proactive conservation interventions. [8].

By integrating IoT, AI, and RFID, this project proposes a scalable Wildlife Tracking and Health Monitoring System, starting with mountain gorillas in Bwindi but adaptable to other species and ecosystems. This approach shifts conservation from reactive to preventive strategies, ensuring timely interventions to safeguard animal health and enhance long-term survival prospects for endangered wildlife worldwide. [9]

1.3 Problem statement

The escalating threat of extinction to global wildlife populations, exemplified by the endangered mountain gorillas in Bwindi Impenetrable National Park, underscores the urgent need for advanced conservation technologies. Current monitoring methods, which rely heavily on human observation, are inconsistent, labor-intensive, and limited in scope, often failing to detect critical health issues such as illness, pregnancy, or stress in a timely manner [10]. These limitations are particularly critical in Bwindi, which hosts over half of the world's remaining mountain gorilla population, where frequent disease-related mortalities and delayed interventions continue to jeopardize their survival [11]. Moreover, traditional tracking methods pose risks of human-to-animal disease transmission and are impractical in Bwindi's dense, rugged terrain, hindering effective conservation efforts [12]While the immediate focus is on mountain gorillas, the challenges of inefficient monitoring and delayed health interventions are prevalent across many endangered wildlife species globally. To address these issues, there is a critical need to develop an integrated AI and RFID-based Wildlife Tracking and Health Monitoring System that leverages simulated IoT sensor data to enable real-time, non-invasive monitoring, analysis, and prediction of health and behavioral patterns. This system aims to facilitate early detection of health issues, enhance conservation decision-making, and provide a scalable solution adaptable to other wildlife species beyond mountain gorillas in Bwindi.[13]

1.4 Objectives

1.4.1 General Objective

To design and simulate an AI and RFID-based Wildlife Tracking and Health Monitoring System for monitoring the health and behavior of Wild Animals

Specific Objectives

- To collect and simulate IoT sensor data representing key health and behavioral parameters such as temperature, heart rate, feeding frequency, sleep duration, and hormonal levels.
- To develop an AI model capable of analyzing IoT sensor data to detect various health conditions and behavioral states such as sickness, pregnancy, and heat cycles.
- To integrate RFID technology for accurate identification and real-time location tracking of individual animals within their natural habitat.
- To test and validate the developed system in terms of accuracy, efficiency, and usability using simulated data from wildlife species (e.g., mountain gorillas).

1.5 Research Questions

1. How can simulated IoT sensor data be applied to monitor the health and activity of Wild Animals in National parks?

2. In what ways can AI analyze IoT data to detect sickness, pregnancy, or abnormal behavior?

3. How can RFID be used to accurately identify and track the locations of individual Wild Animals?

4. How can the integration of AI and RFID improve wildlife monitoring efficiency and conservation outcomes?

1.6 Project significance

The development of an AI and RFID-based Wildlife Tracking and Health Monitoring System holds profound significance for wildlife conservation, initially targeting the endangered mountain gorillas of Bwindi Impenetrable National Park, with the potential for broader application to other wildlife species globally. The significance of this study is outlined through its value proposition, innovation, scope, and conservation components, as detailed below.

1.6.1 Value proposition

This system aims to provide a comprehensive, real-time solution for monitoring the health and movements of wildlife, starting with mountain gorillas in Bwindi. By integrating IoT sensors, AI analytics, and RFID technology, it delivers critical health data e.g., heart rate, body temperature, and hormonal levels and precise location tracking, enabling early detection of illness, stress, or reproductive states [**?**]The system is designed for simplicity and accessibility, offering conservationists, park rangers, and researchers a user-friendly dashboard to access actionable insights. It targets stakeholders involved in wildlife conservation, including park authorities and conservation organizations, providing a scalable tool to enhance decision-making and ensure the long-term survival of endangered species.

1.6.2 Innovation

For the benefit of wildlife conservation, this study introduces an innovative integration of IoT, AI, and RFID into a unified system, a novel approach not widely implemented for specific endangered species like mountain gorillas [3]Unlike traditional monitoring methods, which are labor-intensive and risk disease transmission [12] this system leverages simulated IoT data to develop and test AI models that predict health and behavioral patterns, coupled with RFID for accurate individual tracking. The system's scalability allows adaptation to other species and habitats, revolutionizing wildlife monitoring by providing a centralized, technology-driven platform for real-time data analysis and conservation management.

1.7 Scope

This section delineates the coverage of the project in terms of time, geographical focus, impact, and conservation components.

1.7.1 Time scope

The project will be conducted over a period of six months, from May to November 2025, encompassing the design, simulation, development, and evaluation of the AI and RFID-based system using simulated IoT data.

1.7.2 Geographical scope

The study focuses on Bwindi Impenetrable National Park, Uganda, a critical habitat hosting nearly half of the world's mountain gorilla population [1]. The system is designed with simulated data specific to Bwindi's terrain and gorilla population but is structured to be adaptable for other wildlife species and conservation areas globally.

1.7.3 Impact

The project targets conservationists, park rangers, and researchers who utilize computing and data-driven tools for wildlife management. By providing real-time health and location data, the system simplifies monitoring processes, reduces the costs and risks associated with human-based tracking, and enhances conservation outcomes through early interventions and informed decision-making [14]. Its scalability ensures potential benefits for diverse species and ecosystems worldwide.

1.7.4 Conservation component

The researcher focuses on developing a customized, technology-driven system to meet the urgent needs of wildlife conservation, as highlighted in the problem statement. Traditional monitoring methods are inefficient and risky, often leading to delayed interventions and increased mortality rates [15]. This system addresses these challenges by providing a centralized platform that integrates health and location data, enabling conservationists to access verified, real-time information about individual animals. The researcher aims to implement a sustainable solution that supports proactive conservation strategies, potentially through partnerships, funding, and collaboration with conservation organizations to ensure scalability and long-term impact.

Chapter 2

Literature Review

2.1 Introduction

This chapter synthesizes existing research on the application of Internet of Things (IoT), Artificial Intelligence (AI), and Radio Frequency Identification (RFID) technologies in wildlife monitoring, with the goal of designing a scalable Wildlife Tracking and Health Monitoring System applicable to diverse wildlife species globally. The mountain gorillas of Bwindi Impenetrable National Park serve as a key example to illustrate the system's potential, but the focus is on addressing broader wildlife conservation challenges. This review highlights advancements, challenges, and gaps, positioning the study to develop an integrated, technology-driven solution for global wildlife conservation.

2.2 Literature in Relation to Objective 1

Reliable and continuous data collection is essential for effective wildlife monitoring across diverse species and habitats. IoT technology has transformed ecological research by enabling the use of wearable sensors to capture physiological and behavioral parameters, such as heart rate, body temperature, feeding frequency, sleep duration, and hormonal levels [3]. For example, studies on large mammals like elephants and zebras have utilized IoT-enabled collars with accelerometers and GPS to classify behaviors such as feeding, resting, and migration with high accuracy [16]. Similarly, bio-loggers on marine mammals, such as seals, have recorded heart rate and temperature to monitor responses to environmental changes [17]. Direct data collection from wildlife, particularly endangered species, is often constrained by ethical concerns, logistical challenges, and the risk of disturbance in varied habitats, such as dense forests or remote savannas [18] . To overcome these limitations, researchers employ simulated IoT datasets to replicate realistic physiological and behavioral patterns, such as heart rate e.g., 60–120 bpm for mammals, body temperature e.g., 36–39°C, and activity levels [19]. For instance, simulated data has been used to model behavioral variations in ungulates and primates, enabling algorithm development for detecting anomalies like illness or reproductive states without impacting animals [20]. This study leverages simulated IoT data to represent health and behavioral parameters, using mountain gorillas as an example but designing a framework scalable to diverse species, from terrestrial mammals to marine life.

2.3 Literature in Relation to Objective 2

AI, particularly machine learning and deep learning, has advanced wildlife monitoring by enabling automated analysis of complex IoT sensor data to detect health conditions and behavioral states across species [21]. Models like Random Forests and Long Short Term Memory networks excel at processing time-series data to identify patterns indicative of sickness, stress, pregnancy, or heat cycles [3]. For example, Long Short Term Memory models have been applied to analyze movement and physiological data in livestock, detecting early disease signs with high precision, with transferable applications to wildlife such as deer and big cats [22]. Similarly, AI-driven analysis of hormonal and activity data has identified reproductive states in mammals, supporting conservation strategies for species like rhinos and elephants [23]. Challenges in AI application include limited labeled datasets, inter-species variability, and environmental noise, which can reduce model accuracy [24]. Hybrid approaches combining ecological domain knowledge with ML techniques enhance model robustness and interpretability [21]. Using mountain gorillas as an illustrative case, this study develops an AI model, such as a Random Forest classifier, to analyze simulated IoT data for detecting health and behavioral anomalies, with a scalable design applicable to diverse wildlife, including birds, marine mammals, and large carnivores.

2.4 Literature in Relation to Objective 3

RFID technology is widely used in wildlife conservation for accurate identification and real-time tracking of individual animals across various ecosystems [25]. RFID systems, available as passive, semi-passive, or active tags, have been employed to track species like migratory birds, small mammals, and large herbivores, linking movement data to individual identities for studying habitat use and social dynamics [26]. When integrated with IoT sensors, RFID enables the correlation of physiological data with specific animals, enhancing health monitoring precision for species ranging from turtles to big cats [27]. In challenging habitats, such as dense forests or wetlands, RFID signal interference from vegetation or water requires hybrid systems combining RFID with technologies [28]. Ethical considerations, such as non-invasive tag attachment, are critical to minimize disturbance, particularly for sensitive species [29]. Using mountain gorillas as an example, this study simulates RFID logs integrated with IoT health data to ensure accurate identification and tracking, designing a system adaptable to diverse species and habitats, from savannas to marine environments.

2.5 Literature in Relation to Objective 4

Testing and validation are critical to ensure the accuracy, efficiency, and usability of wildlife monitoring systems across species and ecosystems. Literature recommends a multi-tiered approach: algorithmic validation, system-level testing, and user-level evaluation [30]. Algorithmic validation assesses model performance using metrics like accuracy, precision, recall, and F1-score on simulated or labeled datasets [31]. System-level testing evaluates technical reliability, including communication stability and data loss rates, in diverse environments like forests, grasslands, or aquatic systems [32]. User-level validation ensures that visualization tools, such as dashboards, are intuitive for conservationists and wildlife managers [33]. Simulation-based validation is particularly valuable for wildlife, allowing researchers to test system robustness under conditions like network failures or sensor errors without risking animal welfare [34]. For example, simulated datasets have validated AI models for detecting health anomalies in species like antelopes and primates, ensuring reliability before field deployment [35]. This study employs simulation-based validation to test the integrated AI and RFID system, using mountain gorillas as an example but designing a framework scalable to other species, ensuring accuracy, efficiency, and usability across diverse conservation contexts.

2.5.1 Research Gap

While IoT, AI, and RFID have been applied individually in wildlife monitoring, there is a significant gap in research integrating these technologies into a unified, real-time system for comprehensive health and behavioral monitoring across diverse wildlife species [3]. Existing studies often focus on single technologies or specific species, such as IoT for marine mammals or AI for large herbivores, without combining them into a cohesive platform [21]. Furthermore, few studies address the scalability of such systems to varied habitats and species, from terrestrial to aquatic ecosystems [36]. This research bridges this gap by designing and simulating an integrated system that combines IoT for continuous data collection, AI for intelligent analysis, and RFID for precise tracking, presented through a user-friendly dashboard. Using mountain gorillas as an illustrative case, the system is designed to be extensible to global wildlife populations, advancing conservation efforts across diverse ecosystems.

Chapter 3

Methodology

3.1 Introduction

This chapter describes the methods and approaches used in designing and developing the system. It outlines the software development model adopted, types of data used, methods and tools used for data collection, system assumptions, as well as the software and hardware requirements. It also includes the system's contextual and flow diagrams, and the database design used in building the system.

3.2 The Prototype methodology

Prototyping is a software development model that involves building an early approximation (prototype) of a system or product to visualize the components and gather user feedback before full-scale development. According to [Ref], prototyping helps refine requirements through iterative feedback loops with users.

This study adopted the prototyping model because the project involves a combination of AI model development and user interface deployment. The system required iterative testing and refinement especially in the model prediction interface and the integration of RFID tracking datato improve user experience and system accuracy. The model is suitable for AI-based systems where user feedback influences design changes at every stage.

3.2.1 Phases of Prototyping Used in the Project

Requirement gathering: Initial health parameters, sensor data features, and tracking requirements via RFID were identified.

Quick design: A simple user interface using Streamlit was created for data input, output display, and an integrated dashboard for tracking.

Prototype building: The machine learning model was trained using Google Colab and integrated into the web application. RFID data simulation and mapping functionalities were added.

User evaluation: The system was tested using simulated wildlife sensor and RFID tracking data.

Refinement: The design, prediction output, and tracking visualization were improved based on results.

Final product: A working AI-powered web application with integrated health and tracking features was deployed.

3.3 Data Types

This study used both primary and secondary data sources:

Primary Data:

Simulated IoT Sensor Data: Generated to mimic physiological wildlife measurements such as heart rate, body temperature, and activity level. These were created based on real-life sensor patterns and expert knowledge.

Simulated RFID Tracking Data: Generated to mimic the spatiotemporal data from

RFID tags and fixed readers placed in key locations (e.g., watering holes, feeding zones). This data includes Animal ID, Reader Location, Timestamp, and Signal Strength.

Secondary Data:

Relevant datasets and academic literature from online repositories and published journals were consulted to support the simulation, model training process, and understanding of animal movement patterns.

3.4 Methods of Data Collection

To collect information about how real-world systems operate and understand the best way to simulate IoT and RFID wildlife data:

Interviews: Conducted with wildlife experts, park rangers, and tracking specialists to understand what health indicators are typically monitored and how location data is used for conservation and health assessment.

Questionnaires: Distributed digitally to conservation officers and researchers to collect feedback on what kind of prediction interface and tracking dashboard would be most useful.

3.5 Data Collection Tools

Interview Guide: A structured set of open-ended questions used to guide discussions with wildlife professionals, now including questions on tracking and movement analysis.

Checklists: Used to identify important features that needed to be included in the simulated sensor data, RFID data, and user interface.

Questionnaire: A set of structured questions distributed via Google Forms to gather broader feedback on both health monitoring and tracking features.

3.6 Assumptions Made by the Researcher

The system users will have access to basic computer skills.

Users will have simulated or real IoT data for input.

The system will have access to RFID tracking data from field readers.

The system will be hosted in an environment with consistent internet access.

Necessary software tools like Streamlit, TensorFlow, and Colab are available and accessible.

The system will be primarily used by researchers and wildlife administrators.

3.7 Tools Used in Software Design

3.7.1 Software Tools

Google Colab: Used for training the deep learning model using TensorFlow.

TensorFlow and Keras: Used to build and train the neural network for health classification.

Pandas and Scikit-learn: For data preprocessing and standardization of both sensor and RFID data.

Streamlit: To build and deploy the web interface for model interaction and the integrated tracking dashboard.

Python with Geopandas/Folium/Plotly optional but recommended: Main programming language for backend development and for creating visualizations of animal movement on a map.

Jupyter Notebook (.ipynb): For exploratory data analysis and model training.

3.7.2 Hardware Tools

Laptop Computer: Minimum specs: 8GB RAM, Intel Core i5 processor, 512GB SSD.

Cloud Infrastructure: Google Drive and Google Colab were used to avoid local computational limitations.

3.8 System Design

3.8.1 System Flow Chart

The flowchart below explains how the system works, integrating both health and tracking data streams:

3.8.2 Logical Database Design

While the system doesn't use a full-fledged database, the data is managed in structured formats: Simulated input CSV files with fields: temperature, heart rate, movement, etc. Simulated RFID CSV files with fields: animal id, location, timestamp.

Output health status: Healthy, Sick, or Critical.

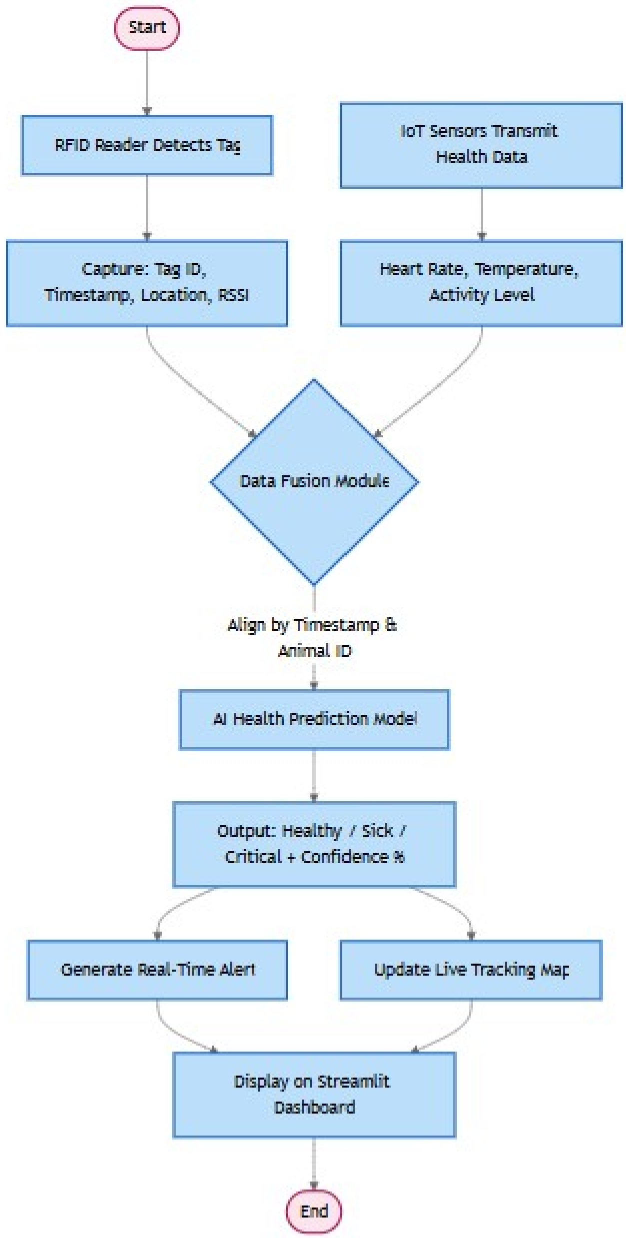

Fig. 3.1: The Flow chart

3.8.3 Physical Database Design

The CSV file acts as the physical datasource. For future development, a database like SQLite or Firebase can be integrated to store historical predictions, usersessions, and animal tracking history.

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