Artificial Intelligence-based detection and deterrence systems: A Case of Mwendwa Farm

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DECLARATION AND APPROVAL

STUDENT

I, Mwendwa Samuel, declare that this research proposal is my original work and that it has not been presented in any other university or institution for academic credit.

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UNIVERSITY SUPERVISOR'S APPROVAL

This project has been submitted with my approval as university supervisor.

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HEAD OF DEPARTMENT'S APPROVAL

This project has been submitted for examination with my approval as university supervisor.

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DEDICATION

This research project is entirely dedicated to our family, friends, colleagues and lecturers who made it successful from the time it commenced till the end.

Abstract

The perennial issue of animal intrusion into farmlands has persisted throughout the annals of agricultural history, leading to substantial damages to crops and severe economic losses for farmers. This relentless challenge necessitates innovative and effective solutions to mitigate its impact. This research is dedicated to the resolution of this age-old issue, focusing on the twin objectives of precise animal identification and proactive deterrence to safeguard farmers' livelihoods and curtail agricultural losses. The paramount aim of this research is to engineer an AI-based detection and deterrence system meticulously tailored to thwart animal intrusion on farmlands. By harnessing cutting-edge technology, this system is adept at efficiently identifying and deterring animals, serving as a steadfast protector of farmers' interests and a bulwark against agricultural losses. The research will encompass the following multifaceted functionalities: Motion Sensing and Imaging: The system is engineered to seamlessly sense motion through strategically placed sensors, instantly capturing images through integrated cameras upon motion detection, advanced AI identification: State-of-the-art AI techniques, encompassing computer vision and sensor technologies, will be harnessed to construct a robust animal detection system. This system will be capable of recognizing diverse elephant species based on the images captured, real-time farmer alert: Upon identifying an elephant that poses a threat to the farm crops, the system will trigger immediate alerts to the farmer. This real-time communication ensures that farmers are promptly informed of potential risks, deterrence activation: In the event of a recognized threat, the system is empowered to automatically activate available deterrence mechanisms, serving as a formidable barrier against animal intrusion. The research leverages cutting-edge AI techniques, converging computer vision and sensor technologies, to establish a formidable animal detection system. At its core, the system integrates a user-friendly mobile application built in java for the front-end, affording farmers the ability to monitor their farms in real-time. This mobile application ensures immediate alerts are disseminated to farmers when animals approach, enhancing their preparedness to combat potential threats. The back-end of the system is intricately engineered, seamlessly blending AI algorithms and data analytics. Developed using python, it serves as the processing hub for data streaming from cameras strategically deployed across the farm. This back-end intelligence enables the automatic and remote activation of deterrence mechanisms, further fortifying the protection of farmlands. In conclusion, this research offers an all-encompassing solution to the longstanding predicament of animal intrusion into farmlands. By embracing advanced technology, innovative AI, and real-time communication, it strives to provide farmers with the means to protect their crops effectively. Ultimately, the research endeavors to significantly reduce agricultural losses, reinforce food security, and foster the harmonious coexistence of agriculture and wildlife, all while placing ecological preservation at its core.

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Definition of Key Terms

Application Programming Interface: A set of rules and protocols that allows different software applications to communicate with each other.

Artificial Intelligence: The simulation of human intelligence processes by machines, including learning, reasoning, problem-solving, perception, and language understanding.

Data Flow Diagram: A graphical representation of the flow of data through an information system, illustrating how data is input, processed, stored, and output.
Database Management System: Software that enables users to define, create, maintain, and control access to databases.

Global Positioning System: A satellite-based navigation system that provides location and time information anywhere on or near the Earth.

Human-Elephant Conflict: Refers to situations where human activities intersect with elephant habitats, leading to conflicts such as crop raiding, property damage, and sometimes human injuries or fatalities.

Information and Communication Technology: An umbrella term that includes any communication device, application, or network encompassing components such as hardware, software, and telecommunications technology.

Institute of Electrical and Electronics Engineers: A professional association for electronic engineering and electrical engineering, known for developing standards in various industries.

Intelligent Animal Repelling System: A system designed to deter animals, typically wildlife, using intelligent technologies such as sensors, alarms, and sometimes artificial intelligence to prevent human-animal conflicts.

Internet of Things: A network of interconnected devices embedded with sensors, software, and other technologies that enables them to collect and exchange data over the internet.

IR Sensor: Infrared Sensor: A sensor that detects infrared radiation emitted or reflected by objects, commonly used for proximity sensing, motion detection, and temperature measurement.

Kenya Wildlife Service: A government agency in Kenya responsible for the conservation and management of wildlife resources in the country.

Machine Learning: A subset of artificial intelligence that involves the development of algorithms and statistical models that enable computers to learn from and make predictions or decisions based on data without being explicitly programmed.

Multilayer Perceptron: A type of artificial neural network composed of multiple layers of nodes, including an input layer, one or more hidden layers, and an output layer.
Pulse Width Modulation: A technique used to encode analog information in a digital signal by varying the width of the pulse.

Quality Assurance: The systematic process of ensuring that a product or service meets specified requirements and quality standards.

Quick Response Code: A two-dimensional barcode that can be read by a smartphone camera, typically used for storing URLs or other information for quick access.

Radio-Frequency Identification: A technology that uses electromagnetic fields to automatically identify and track tags attached to objects.

Serial Peripheral Interface: A synchronous serial communication interface used for short-distance communication between devices.

Short Message Service: A text messaging service component of most telephone, internet, and mobile device systems. It uses standardized communication protocols to enable mobile devices to exchange short text messages.

Software Engineering: The application of engineering principles to the design, development, maintenance, testing, and evaluation of software and systems.

User Experience: The overall experience a user has when interacting with a product or system, encompassing aspects such as usability, accessibility, and satisfaction.

User Interface: The means through which a user interacts with a computer, website, or application, typically including graphical elements such as buttons, menus, and screens.

World Wide Fund for Nature: An international non-governmental organization working in the field of wilderness preservation and the reduction of human impact on the environment.

CHAPTER ONE

Introduction

1.1 Introduction

This chapter serves as the initiation point of the research, laying the groundwork for the entire study. It begins with a general introduction before delving into the motivation and background that propelled the research forward. The background of the research provides a comprehensive overview of the context, leading to the articulation of the problem statement. The chapter then outlines the specific aim and objectives that guide the research. These objectives are further detailed into the main objective and specific objectives. It then dives into a few research questions. A justification for the research highlights its significance, followed by an explanation of the research scope to define its boundaries. Finally, the chapter concludes by outlining the organization of the research.

1.2 Motivation and Background

The motivation behind embarking on this research journey stems from a deeply personal experience and a candid conversation with a visiting relative. In the course of our conversation, my relative unveiled a tale of unyielding struggle with animals infiltrating their farmlands. Despite investing in traditional fencing, the problem of animal incursion remained a formidable adversary. The introduction of an electric fence initially offered a glimmer of hope, yet it soon became evident that this solution came with its unique set of challenges. The crux of the issue lay in the reliability of the power supply that fueled the electric fence. It became apparent that the existing power source could not cover the entirety of the day and night, leaving significant vulnerabilities during the darker hours. To address this, a battery system was introduced, complemented by solar panels. However, the battery's limitations surfaced as it could sustain the electric fence for merely six hours after nightfall. As the rainy season set in, cloud cover and torrential rains further hampered the efficiency of the solar panels, diminishing the battery's capacity to a mere three hours of operation.

The circumstances necessitated a manual approach to this problem. The electric fence remained switched off for most of the time, only to be activated when the family heard reports of neighboring villages fending off marauding elephants. In these moments, my relatives would rush to the farm, switch on the fence, and face the impending danger. The constant need for vigilance and the high-stakes of manual intervention created an unsustainable and unreliable system. This experience underscored the urgency for an innovative, automated solution to the challenge of farm animal intrusion. It became abundantly clear that the advancements in technology, specifically in the realm of artificial intelligence (AI), held the potential to revolutionize farm animal protection. Through the development of an AI-based detection and deterrence system, it is not merely a mitigation of crop damage and economic losses that is aimed for, but also the enhancement of safety and the empowerment of farmers to respond to threats remotely.

Throughout history, farmers have grappled with the challenge of animal intrusion onto their lands. Various methods were employed to deter animals, from scare tactics and noise-emitting devices to physical barriers. Yet, these approaches were often: labor-intensive**,** these approaches often involved physically patrolling the fields, setting up scarecrows, or deploying personnel to keep a watchful eye. While these methods could be effective to some extent, they demanded a considerable number of human resources and time. Farmers and farm workers had to invest significant effort in maintaining these measures, diverting valuable manpower from other essential farming tasks. Moreover, the effectiveness of labor-intensive methods varied, and it was challenging to provide round-the-clock surveillance, leaving vulnerabilities during nighttime and in remote areas.

Unreliable. Scare tactics, such as loud noises, fireworks, or even physical deterrents like fences or barriers, often had limited and inconsistent success. Wildlife quickly adapted to these methods, rendering them less effective over time. Furthermore, external factors like weather conditions or the absence of constant supervision could lead to their failure. Unreliable deterrence measures meant that farmers could not depend on them to consistently protect their crops, resulting in ongoing losses and frustration.

harmful to both wildlife and the environment. Noise-emitting devices, for instance, could disrupt the natural habitats and behaviors of animals. Physical barriers, while meant to deter animals, could also pose a danger to them, potentially causing injuries or fatalities. Moreover, the widespread use of these methods often led to unintended ecological disturbances, affecting not only the targeted animals but the broader ecosystem. The harm inflicted on both wildlife and the environment underscored the need for more humane and sustainable solutions to the problem of farm animal intrusion.

The advent of technological advancements has ushered in opportunities to develop more sophisticated and humane solutions. Artificial intelligence, in particular, offers a promising platform for addressing the problem of farm animal intrusion. AI's capabilities in image recognition, sensor integration, and real-time response provide an ideal foundation for the creation of a comprehensive detection and deterrence system.

1.3 Research Background

Addressing the challenge of animal encroachment in crop fields requires a multifaceted approach that leverages the latest technological advancements, such as deep learning, IoT, and real-time solutions. This research background draws insights from three key sources: Gowda, R., H., Bindushree R., V., Black, J., Cherbatji, M., Connolly, C., and Haakstad, O. H., to provide a comprehensive overview of the theoretical foundations and technological frameworks relevant to animal encroachment detection and deterrence.

Gowda, R., et al., hailing from the Department of ISE, JSS Academy of Technical Education, Bangalore, India, conducted research that centered on animal encroachment detection using a combination of deep learning and IoT technologies. Their study explored the practical application of artificial intelligence, specifically the utilization of Convolutional Neural Networks (CNNs) to make informed decisions based on input data. They developed a dataset tailored for deep learning and delved into the theoretical underpinnings of the YOLO (You Only Look Once) algorithm and deepSORT (Simple Online and Realtime Tracking). These developments laid the foundation for AI-driven animal encroachment detection, from basic operations to deep learning applications.

Real-time Animal Identification and Deterrence Jake Black's research, "RAID: Real-time Animal Identification and Deterrence," conducted under the supervision of Mohammed Cherbatji and the guidance of Cyril Connolly, focused on the practical implementation of animal identification and deterrence systems. Black's work extended beyond theory to investigate real-time animal identification technologies, aiming to bridge the gap between theoretical frameworks and practical, real-world solutions. The research led to the development of real-time AI-driven systems capable of identifying and deterring animals, addressing the challenge in a tangible and efficient manner.

Deterrence of Animals using Artificial Intelligence In a complementary effort, O. Henrik Haakstad made significant strides in the "Development of System for Deterrence of Animals using Artificial Intelligence." His research was instrumental in exploring how artificial intelligence could be employed to deter animals effectively from specific areas. By harnessing AI techniques, such as Convolutional Neural Networks (CNNs) and the YOLO (You Only Look Once) architecture, Haakstad developed practical mechanisms for animal deterrence. His work provided specific insights into the implementation of AI-based deterrence systems, further enriching the theoretical framework with tangible solutions.

1.4 Problem Statement

Farmers, grappling with the enduring challenge of farm animal intrusion onto their farmlands, face significant barriers to a functional and sustainable agricultural process. This issue occurs in diverse environmental conditions, jeopardizing agricultural productivity. The problem is compounded by traditional animal deterrence methods, which are often labor-intensive, unreliable, and detrimental to both wildlife and the environment. Therefore, there is an urgent need for an innovative solution to protect farmers' livelihoods and foster ethical coexistence between agriculture and wildlife.

1.5 Aim of Research

The primary aim of this research is to develop an advanced AI-based detection and deterrence system that efficiently identifies and deters elephants from entering farmlands. This system seeks to address the persistent issue of farm animal intrusion and, in doing so, it aims at fulfill several critical objectives: Enhancing Agricultural Sustainability. The central aim of this research is to significantly enhance the sustainability of agriculture by providing farmers with a reliable, efficient, and humane solution to the challenge of animal intrusion. By protecting crops from wildlife interference, this system aims to bolster crop yields and reduce economic losses, contributing to the overall sustainability of agricultural practices.

Promoting Harmonious Coexistence. The research aspires to promote a harmonious coexistence between human agriculture and the natural habitats of wildlife. This involves mitigating the need for harmful and labor-intensive deterrence methods, fostering a more balanced interaction between farmers and the environment. The aim is to prioritize the well-being of both farmers and wildlife. Developing Cutting-Edge Technology. A core aim of this research is to harness cutting-edge technologies, including computer vision, sensor integration, and real-time response, to create an innovative system that sets new standards in the field of farm animal intrusion deterrence. The research aims to push the boundaries of technological solutions to address complex real-world challenges.

Providing Real-Time Protection. The system's aim is to offer continuous, real-time protection to farmlands. By identifying and deterring animals promptly, it ensures that potential threats are neutralized before they can cause damage. The system operates during both day and night, offering uninterrupted coverage. Empowering Farmers. The research aims to empower farmers by providing them with an easy-to-use, accessible, and efficient tool. The AI-based system, complemented by a user-friendly mobile application, enables farmers to monitor their farmlands remotely and respond swiftly to potential threats, thereby reducing the need for manual intervention.

The aim of this research extends beyond the development of a technological solution. It encapsulates the broader objectives of enhancing agricultural sustainability, promoting ethical coexistence, pushing the boundaries of technology, and empowering farmers.

1.6 Objectives of the Research

1.6.1 Main Objective of the Research

The main objective of this research is to develop an Artificial Intelligence-based detection and deterrence system for farmers who are plagued with the age-old problem of animal intrusion in their farms.

1.6.2 Specific Objectives of the Research

At the end of the study, I want the application to:

i. Process the image and correctly identify elephants
ii. Send an alert to the farmer about elephant detected
iii. Activate the deterrence system on farmer’s command remotely

1.6.3 Research Questions

How effective are AI-based detection systems in accurately identifying different species of animals in real-time?

What machine learning algorithms and computer vision techniques are most suitable for processing images captured by sensors in agricultural environments for animal detection?

How can the integration of motion sensors and cameras in crop fields be optimized to enhance the precision and reliability of animal detection?

What are the key challenges and limitations in the current state-of-the-art AI technologies for animal encroachment detection, and how can they be addressed?

In what ways can real-time communication methods, such as alerts to farmers, be improved to ensure timely response to potential threats posed by animals in crop fields?

What deterrence mechanisms have shown the highest efficacy in repelling various types of animals, and how can these be integrated into an automated system triggered by AI-based detection?

How scalable and feasible is the proposed integrated system for implementation in diverse agricultural settings, considering variations in crop types, field sizes, and environmental conditions?

What ethical considerations need to be addressed in the deployment of AI-based animal detection and deterrence systems in agricultural landscapes, particularly concerning wildlife conservation?

1.7 Justification of Research

The foundation of this research project is deeply rooted in the pioneering work of Hendrick Haakstad, whose groundbreaking research demonstrated the effectiveness of utilizing AI to accurately identify animals, particularly cats. Haakstad's work laid the groundwork for advancements in animal identification systems, showcasing the potential of AI-driven solutions in addressing wildlife intrusion on farmlands.
Building upon Haakstad's findings, this project seeks to extend the capabilities of

existing deterrence systems, such as the one developed by Amadi. Amadi's deterrent system, which utilizes sound frequencies, has proven to be effective in repelling small animals like deer. However, the challenge lies in scaling up this technology to deter larger mammals, particularly elephants, which pose a significant threat to agricultural lands.

To address this challenge, this research project aims to enhance the existing frequency-based deterrence system by expanding the range of frequencies used. While Amadi's system operates within a specific frequency range, typically effective against smaller animals, this project proposes to extend the frequency range to encompass frequencies in the 10,000 Hz to 16,000 Hz range, which has been seen to work against elephants (Shrivastava, S., & Buchholtz, E. 2023). By broadening the spectrum of frequencies utilized, the deterrent system can target larger mammals like elephants more effectively.

The utilization of AI in conjunction with an expanded frequency-based deterrence system represents a significant advancement in wildlife intrusion deterrence technology. By leveraging AI for animal identification and integrating a more comprehensive range of frequencies for deterrence, this project aims to provide farmers with a robust and reliable solution to protect their farmlands from animal encroachment. In summary, this research project builds upon the foundational work of Hendrick Haakstad and the innovative deterrence system developed by Amadi. By advancing these technologies and extending their applicability to deter larger mammals like elephants, the project seeks to enhance agricultural sustainability and mitigate the detrimental impact of wildlife intrusion on farmlands.

1.8 Scope of Research

The primary purpose of this research is to develop, implement, and evaluate an Intelligent Animal Repelling System for mitigating human-elephant conflict in Taita-Taveta County, Kenya. The study aims to provide a sustainable and ethical solution that ensures the safety of both human communities and elephants, contributing to the broader field of conservation technology. The target population for this study comprises communities residing in Taita-Taveta County, particularly those facing challenges associated with human-elephant conflict. The characteristics of this population include individuals who rely on agriculture and inhabit areas prone to elephant intrusions. The study will be conducted in Taita-Taveta County, Kenya, specifically, Mwendwa farm where human-elephant conflict is a pressing issue. This location is crucial for testing the efficacy and adaptability of the Intelligent Animal Repelling System in a real-world context.

The research will be conducted over an 8-month period, allowing for comprehensive data collection, system implementation, and evaluation. This timeframe ensures a thorough understanding of seasonal variations in human-elephant conflict and provides insights into the long-term effectiveness of the proposed system. The justification for this research lies in the urgent need for innovative, ethical, and locally adaptable solutions to human-elephant conflict. Taita-Taveta County serves as an ideal location due to its persistent challenges with elephant intrusions, making the study directly relevant to the needs of the affected population. The 8-month duration allows for a comprehensive examination of the system's performance, ensuring robust findings and insights.

By focusing on a population directly impacted by human-wildlife conflict, this research aligns with the broader goal of fostering coexistence between communities and wildlife. The incorporation of relevant theories enhances the theoretical framework, contributing to the academic discourse on conservation technology and conflict resolution. Overall, this study holds practical implications for wildlife conservation, community well-being, and the advancement of humane technologies in the field.

1.9 Research Organization

This research is organized into seven comprehensive chapters, each serving a distinct purpose to guide the reader through the study systematically. Chapter 1 – Introduction: This chapter lays the groundwork by introducing the research topic, outlining the motivations, background, problem statement, objectives, and justifications for the research. It provides a clear framework for understanding the scope and significance of the study. Chapter 2 – Review of Related Work: This chapter delves into existing knowledge by tracing the historical context of the research topic, reviewing related work, and identifying gaps that the current research aims to fill. It explores the emergence of trends within the research area, providing a thorough background for the subsequent methodology. Chapter 3 – Research Methodology: This chapter details the methodologies employed in the research. It includes approaches for literature review, requirement specification, data collection, and various analysis techniques such as interviews and questionnaires. Additionally, it covers system analysis, design, implementation, testing, and deployment, offering a comprehensive overview of the research processes.

Chapter 4 – System Analysis: Here, the current systems are described and analyzed. The chapter evaluates the strengths and weaknesses of these systems, conducts a feasibility study, and presents process logic designs using flow charts and diagrams. Chapter 5 – System Design: This chapter describes the proposed systems in detail, highlighting their strengths and weaknesses. It includes a thorough requirement analysis covering functional, non-functional, user, and usability requirements. Conceptual architecture, process logic design, and database design are also discussed. Chapter 6 – Implementation System & Testing: This chapter outlines the implementation phase, providing system screenshots and detailing the testing plan. It covers various testing techniques, including unit, integration, system, and acceptance testing. An evaluation plan is also discussed to assess effectiveness, performance, usability, and user acceptance.

Chapter 7 – Conclusions, Findings & Recommendations: The final chapter summarizes the research findings, discusses challenges encountered, and provides future recommendations. It covers technical limitations, algorithmic complexities, hardware compatibility, data privacy, and operational reliability. The chapter concludes with suggestions for enhanced connectivity solutions, advanced algorithms, integrated sensors, data privacy measures, scalability, and continuous monitoring. This structured organization ensures a logical flow, guiding the reader through a coherent and comprehensive exploration of the research journey.

CHAPTER TWO

Review Of Related Work

2.1 Introduction

This chapter delves into the existing body of knowledge relevant to the research topic. It begins with an introduction to the chapter, followed by a historical overview of the research topic. A comprehensive review of related work and prototypes/systems on a global, regional and local scale is presented, unveiling emerging trends and patterns in the research area. The chapter identifies gaps in the current body of knowledge that the current research aims to fill and summarizes the chapter's content.

2.2 History of the Research Topic

The history of the research topic traces the enduring challenge of farm intrusion by animals, impacting crops and causing economic losses. Early agricultural practices relied on manual methods, utilizing physical barriers like fences and scarecrows to deter animals (Kiffner et al., 2021). With the advent of IoT, sensor technologies were integrated into agriculture, marking a shift toward more advanced monitoring systems (Adami et al, 2021). These newer systems aim for harmonious co-existence between man and animal, reduced economical losses for farmers and protection of wildlife. As technology advanced, the intersection of AI and IoT paved the way for intelligent systems capable of autonomously detecting and deterring animals in real-time (Adami et al, 2021). This transition from traditional approaches to technology-driven solutions is evident in the progression of research in the field.

Studies such as "A Review on Animal Encroachment Detection in Crop Fields Using Deep Learning and IoT" (Thanushree Gowda et al., 2022) and projects like "RAID: Real-time Animal Identification and Deterrence" (Black, 2023) and "Development of System for Deterrence of Animals using Artificial Intelligence" (Haakstad, 2021) have played pivotal roles in shaping the landscape of animal detection and deterrence research. In recent years, researchers have employed various techniques for the detection and deterrence of animals, showcasing the diversity of approaches to address this persistent issue. One notable method involves the use of Convolutional Neural Networks (CNNs) for real-time detection across different animal species (Bhatt, D., et al., 2021). This technology has demonstrated effectiveness in accurately identifying animals, forming a crucial component of modern animal intrusion detection systems. Additionally, Haakstad (2021) introduced an innovative approach by incorporating CNNs into a system that not only detects and classifies animals but also employs a water turret for deterrence. This integration of detection and deterrence mechanisms provides a comprehensive solution to mitigate the impact of animal encroachment on farmlands.

Furthermore, some researchers have explored the combination of region-based Convolutional Neural Networks (R-CNN) and You-Only-Look-Once (YOLO) architectures for animal detection (Wang, T., et al., 2019). YOLO, in particular, stands out as a state-of-the-art algorithm for real-time object detection, reframing the problem as a regression task and computing bounding box probabilities and class predictions directly from pixel input. As the research delve into deterrence mechanisms, it's noteworthy that existing methods have primarily focused on visual or water-based deterrents. However, there is a research gap in the deterrence of larger animals like elephants using sound waves. While various deterrents have been applied to animals, especially in the context sound waves (Adami, D., et al. 2021), there is a notable absence of studies investigating the effectiveness of sound waves, particularly on elephants. Expressing interest in using sound waves as a deterrence mechanism for elephants could be a novel and an impactful contribution to the field. This approach aligns with the objective of developing an AI-based detection and deterrence system in the research. It not only diversifies the deterrence methods but also addresses a specific gap in the current literature, potentially offering a more humane and effective solution for protecting crops from elephant intrusion. This historical context forms the foundation for the current research, which aims to contribute to the evolution of methods and technologies for safeguarding crops from wildlife intrusion.

2.3 Review of Related Work

Many researches have researched this topic and the ones that stood out to me included: Development of System for Deterrence of Animals using Artificial Intelligence by Ole Hendrick Haakstad, 2021. This project sought to develop a harmless and accurate system for keeping cats away from personal property. In the research, the utilization of YOLOv4-tiny is driven by the objective of enhancing detection speed. YOLOv4-tiny, a variant of the YOLO algorithm, prioritizes computational efficiency without compromising accuracy. This choice is motivated by the need for faster processing, crucial in real-time applications. By opting for YOLOv4-tiny (Jiang, Z., Zhao, L., Li, S., & Jia, Y. 2020), the research aligns with the goal of advancing animal detection speed, emphasizing practicality and suitability for scenarios with hardware limitations. It can work on low-end hardware efficiently and fast reducing cost of hardware (Haakstad, O. 2021).

Building upon the foundational work in "Design, Development and Evaluation of an Intelligent Animal Repelling System for Crop Protection Based on Embedded Edge-AI," by Davide Adami, Mike o. Ojo, (Member, IEEE), and Stefano Giordano. The current research seeks to extend the capabilities of the system to address the specific challenge of deterring elephants. While the original work focused on creating an intelligent system for wild boars, roe deer and fallow deer repulsion in crop protection by use of ultra-sounds targeting the specific animals (Ojha, K. S., et al., 2020), the proposed research recognizes the unique characteristics and challenges associated with deterring elephants from agricultural fields. By leveraging the embedded edge-AI framework established in the previous study, the aim is to enhance the system's intelligence and add elephant targeted frequencies to deter elephants, contributing to the broader goal of mitigating human-wildlife conflicts in agricultural settings (Adami, D., et al., 2021).

Detection of Cattle Using Drones and Convolutional Neural Networks by Alberto Rivas, Pablo Chamoso, Alfonso González-Briones, and Juan Manuel Corchado. This research reviews the effectiveness of using drones equipped with Convolutional Neural Networks (CNNs) for cattle detection. It finds that drones overcome limitations of traditional methods by providing efficient access to large areas. CNNs accurately identify cattle due to their ability to learn complex patterns from images. Several CNN architectures, including YOLO and SSD, have been successful. Reported accuracy varies depending on factors like data quality and environment, but can reach 95%. Challenges remain, including limited datasets, diverse environments, and computational costs. This review builds on existing work by focusing on CNN-based approaches, analyzing recent advances, and discussing future directions by expanding the dataset to detect elephants too.

2.4 Review of Related Prototypes, Systems [from global to local]

Jake Black's RAID system focuses on real-time animal identification and deterrence. It records real-time footage, pre-processes it and filters out the owner's cat. If any cat other than the owner's is detected, it activates a water turret, which splashes the cat and it leaves the property.

Ole Henrik Haakstad's work centers on an AI-based deterrence system for wild boars, roe deer and fallow deer. It uses machine learning algorithms and mechanisms which detects and classifies the animal, if the animal is among the blacklisted, the deterrence system. The deterrence

Sandra Maryanne's Ndovucare is a multi-sensory device designed to address the specific challenges posed by elephants in Taita-Taveta County. The device employs sensors, LED lights, and sound to detect and deter elephants effectively. The operational sequence involves the sensors detecting elephant presence, triggering the illumination of LED lights to indicate their proximity, emitting a disturbing sound via a siren, and sending SMS notifications to both the local community and the Kenya Wildlife Service. This comprehensive approach not only alerts communities but also acts as a deterrent, showcasing an integrated solution to human-elephant conflict.

2.5 Emerging Trends and Patterns in the Research Area

The dynamic landscape of human-wildlife conflict mitigation is characterized by ongoing advancements and evolving trends. In this section, we explore the emerging patterns and trends within the research area, shedding light on key developments that shape the trajectory of innovative solutions for crop protection. An emerging trend in recent research involves the integration of Edge-Artificial Intelligence (Edge-AI) in deterrence systems. This paradigm shifts towards decentralized AI processing at the edge devices, such as sensors or cameras in the field, enables real-time decision-making without relying heavily on centralized cloud systems. This trend aligns with the need for swift responses in deterring wildlife intrusions, ensuring timely actions for crop protection.

Researchers are increasingly exploring the fusion of multiple detection technologies to enhance the accuracy and reliability of wildlife identification. Integrating sensor data, camera imagery, and possibly acoustic signals allows for a more comprehensive understanding of the environment. This trend reflects a holistic approach, aiming to minimize false positives and improve the overall efficiency of detection and identification systems. The utilization of machine learning algorithms for adaptive deterrence represents a significant trend in recent studies. Instead of relying on predefined deterrence strategies, machine learning enables systems to adapt and optimize deterrence mechanisms based on the observed behavior of wildlife. This adaptive approach holds promise in creating more effective and targeted deterrence, considering the varied responses of different species.

A notable trend is the emphasis on human-centric design in the user interfaces of wildlife detection and deterrence systems. As these technologies become integral tools for farmers, the user experience and accessibility play a crucial role. Recent research acknowledges the importance of intuitive interfaces, mobile applications, and user-friendly dashboards, ensuring that farmers can easily interpret alerts and manage deterrence mechanisms. The research area is witnessing increased collaboration across disciplines, bringing together experts in wildlife biology, artificial intelligence, agriculture, and environmental science. This interdisciplinary approach ensures a holistic understanding of the complex dynamics involved in human-wildlife conflict. Collaborative efforts contribute to the development of more effective, ethically sound, and environmentally sustainable solutions.

The exploration of emerging trends and patterns demonstrates the vibrant and evolving nature of research in human-wildlife conflict mitigation. The integration of Edge-AI, fusion of detection technologies, adaptive deterrence through machine learning, human-centric design, and cross-disciplinary collaboration collectively paves the way for innovative, context-aware solutions. As we embark on our research journey, we remain attentive to these trends, striving to contribute to the cutting-edge developments that define the future of wildlife management in agricultural landscapes.

2.6 Research Gap to be Filled by the Research

While substantial progress has been made in the domain of human-wildlife conflict mitigation, a critical research gap persists, forming the primary motivation for the current study. This section delineates the specific gap this research aims to address, thereby contributing novel insights to the existing body of knowledge. The prevailing literature extensively covers various wildlife detection and deterrence systems, encompassing species ranging from small mammals to large carnivores. Lack of Sound Wave-Based Deterrence for Elephants. Notably, the research gap extends to the absence of sound wave-based deterrence methods specifically designed for elephants. While sound waves have been explored for deterring certain wildlife species, their application to elephant deterrence remains an uncharted territory. Elephants are known for their acute auditory perception, and leveraging sound waves presents a promising avenue to create a humane, effective deterrence strategy.

2.7 Chapter Summary

In this chapter, we delved into the existing body of literature related to human-wildlife conflict mitigation, with a specific focus on technologies and systems designed for the detection and deterrence of wildlife species in agricultural settings. The exploration commenced with a comprehensive review of seminal works, including “A Review on Animal Encroachment Detection in Crop Fields Using Deep Learning and IoT” by Gowda et al., “RAID: Real-time Animal Identification and Deterrence” by Black, and “Development of System for Deterrence of Animals using Artificial Intelligence” by Haakstad.

The key themes explored in these works revolved around the use of deep learning, IoT, real-time animal identification, and artificial intelligence for detecting and deterring animals in crop fields. Each study contributed unique insights into the development of systems to address the persistent challenge of farm intrusion by wildlife. Notably, Gowda et al. emphasized the integration of sensors and cameras, while Black’s work focused on real-time animal identification using advanced technologies. Haakstad delved into the broader scope of animal deterrence through artificial intelligence.

Upon synthesizing these works, a notable research gap emerged, specifically regarding the absence of tailored deterrence mechanisms for elephants and the limited exploration of sound wave-based deterrence strategies. Recognizing this gap, the chapter culminated in the articulation of the main objectives of the present research, highlighting the need for elephant-specific deterrence, the application of sound waves, context-aware adaptive systems, and the integration of sustainable environmental practices.

In essence, this chapter serves as a foundation for the current research, laying the groundwork by comprehensively reviewing existing literature, identifying research gaps, and delineating the specific objectives that will guide the subsequent phases of this study. The synthesis of prior works not only informs the direction of the research but also positions it within the broader context of human-wildlife conflict mitigation.

CHAPTER THREE

Research Methodology

3.1 Introduction

This chapter outlines the systematic approach taken to conduct the research. It commences by introducing the methodology for the literature review and then details the methodology for requirement specification and data collection. Subsections under the aforementioned cover requirement specification, data collection methods, interviews, questionnaires, and observation. The chapter proceeds to delineate the methodologies for system analysis, design, implementation, testing, and deployment. Each subsection elucidates the specific techniques and approaches employed in the corresponding phase of the research.

3.2 Methodology for Literature Review

The literature review methodology for this research involved a systematic and thorough exploration of scholarly works. Initially, a preliminary search was conducted on reputable platforms such as Google Scholar and IEEE This phase aimed to define key terms and parameters, laying the groundwork for a comprehensive understanding of the research landscape. To ensure the inclusion of high-quality sources, stringent selection criteria were established. Emphasis was placed on factors such as relevance, recency, and credibility. This step was crucial in filtering out sources that might not contribute significantly to the research objectives.

A strategic approach to keyword optimization was adopted, utilizing an iterative process by searching the research questions. This involved refining search terms based on initial findings and feedback, enhancing the precision of the search and uncovering relevant literature. Thematic clustering emerged as a central strategy in organizing the literature. This approach involved grouping works around common themes, methodologies, and findings, providing a structured framework for synthesis. The methodology underwent an iterative refinement process, incorporating regular loops to adapt to emerging trends and insights in the academic discourse. This ensured that the literature review remained responsive to the dynamic nature of the research area. Citation ratio and relevance assessments played a pivotal role in the selection process. A meticulous evaluation was conducted to identify highly impactful works aligned with the research objectives.

Diversification of sources was a key consideration. The methodology emphasized including diverse works from various disciplines to provide a multidimensional perspective on the research topic. A rigorous evaluation of methodologies employed in selected works was undertaken to distinguish studies with methodological rigor from those with potential limitations. Thematic clustering and synthesis were intensified, grouping works based on commonalities in themes, methodologies, and findings. This facilitated the construction of a coherent narrative in the literature review. An iterative review process was established to enable continuous refinement of the literature review. This iterative approach ensures that the review remains up-to-date, responsive to emerging trends, and reflective of the evolving scholarly landscape.

3.3 Methodology for Requirement Specification, Data Collection and Analysis Techniques

3.3.1 Requirement Specification

Requirement specification is a critical process that involves systematically defining and documenting the functionalities, features, and constraints of a system. This phase is foundational as it sets the framework for the entire development process (Leveson, 1994). In the context of our research, requirement specification aims to clearly articulate the expected behavior and capabilities of the AI system for animal detection and deterrence.

The process of requirement specification will involve a combination of literature review, expert consultations, and iterative discussions with stakeholders. The goal is to identify key functionalities such as image processing, alert generation, and deterrence activation. Input from farmers, AI experts, and relevant authorities will be gathered to ensure a comprehensive and user-oriented set of requirements. The outcome of this phase will be a detailed requirement specification document that serves as a blueprint for the subsequent stages of system development. This document will provide a clear roadmap for the integration of AI algorithms, and communication systems.

3.3.2 Data Collection Methods

The data collection process will commence with an extensive literature review to identify existing studies and data sources related to animal behavior, agricultural landscapes, and successful strategies for animal deterrence. This will provide a foundational understanding and guide the selection of data collection methods. Field surveys and direct observations will be conducted to gather first-hand data on local animal behavior patterns and prevalent issues faced by farmers. These surveys will include structured interviews with farmers, wildlife experts, and relevant authorities to capture diverse perspectives.

3.3.3 Interviews

Interviews are a crucial component of the data collection process, providing in-depth insights into participants' perspectives, experiences, and knowledge related to the research topic (Paradis, 2016). Structured, semi-structured, or unstructured interview formats may be employed based on the research objectives (Paradis, 2016). In structured interviews, predetermined questions are asked consistently to all participants, ensuring uniform data collection (Paradis, 2016). Semi-structured interviews allow for flexibility, enabling the exploration of unforeseen insights while maintaining a basic question guide (Paradis, 2016). Unstructured interviews provide an open dialogue, allowing participants to share their thoughts freely (Paradis, 2016).

Structured interviews are suitable for quantitative data collection, whereas semi-structured and unstructured formats are valuable for qualitative inquiries (Paradis, 2016). Interviews facilitate the gathering of rich, nuanced data directly from participants, contributing to a comprehensive understanding of the research area. For the research both will be implemented due to the nature of the project.

3.3.4 Use of Questionnaires

Questionnaires are a widely used research instrument, particularly for collecting data from large groups of individuals efficiently and cost-effectively (Babbie, 2017; Bryman, 2012). They consist of a series of questions designed to gather information on various aspects, including: Demographics: age, gender, income, etc. (Singleton & Straits, 2018), Opinions and beliefs: attitudes towards specific topics, beliefs about particular issues, etc. (DeWalt & DeWalt, 2015) and, behaviors and experiences: past experiences with products or services, current behaviors related to a specific topic, etc. (Babbie, 2017).

Questionnaires come in two main formats: Structured questionnaires: These utilize closed-ended questions with predetermined answer choices, making them ideal for quantitative research and relatively easy to analyze and score (Bryman, 2012). Unstructured questionnaires: These utilize open-ended questions allowing respondents to express their thoughts freely, making them more suitable for qualitative research but often requiring more time and effort for analysis (DeWalt & DeWalt, 2015).

3.3.5 Observation

Observation is a research method that involves systematically observing and recording data about phenomena or events without actively intervening (Babbie, 2017; Bryman, 2012). This method allows researchers to gain firsthand insights into participants' behaviors, interactions, and contexts (Singleton & Straits, 2018). Observations will play a crucial role in understanding the dynamics of animal intrusion in crop fields. By keenly observing the behaviors of animals and the effectiveness of the deterrence system in situ, researchers can gain valuable insights that may not be captured through interviews or questionnaires. Researchers can directly observe behaviors and interactions, reducing the reliance on self-reported data (Babbie, 2017). Observation allows researchers to capture the nuances of behavior and the context in which they occur (Bryman, 2012). In some cases, observation can be conducted without participants even knowing they are being observed, reducing the risk of reactivity (Babbie, 2017). Observation can be a time-consuming method, requiring researchers to be present and attentive for extended periods (Singleton & Straits, 2018). Researchers' interpretations of observations can be influenced by their own biases and preconceptions (Babbie, 2017). The presence of a researcher may alter participants' behavior, making it difficult to observe natural behavior (Bryman, 2012).

3.4 Methodology for System Analysis (current system); DFD, Context diagram, flow charts

This section analyzes the current system described in "Design, Development and Evaluation of an Intelligent Animal Repelling System for Crop Protection Based on Embedded Edge-AI," by Davide Adami and Mike Ojo (2023). This analysis employs Data Flow Diagrams (DFDs), Context Diagrams, and Flow Charts to illustrate the system's existing functionality and identify potential areas for improvement.

3.5 DFD, Context diagram, flow charts, sequence diagram, collaboration diagrams, use case, pseudocodes etc., Early System prototypes (I/O design)

DFD

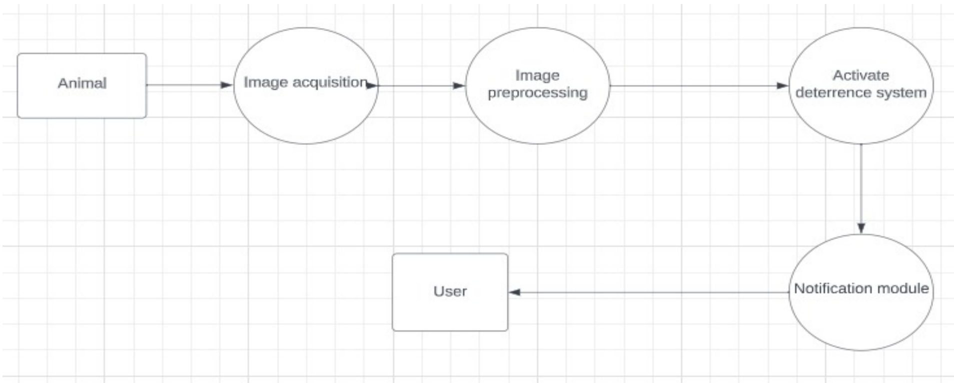

figure 3. 1 Data Flow Diagram (Author, 2024)

Context Diagram:

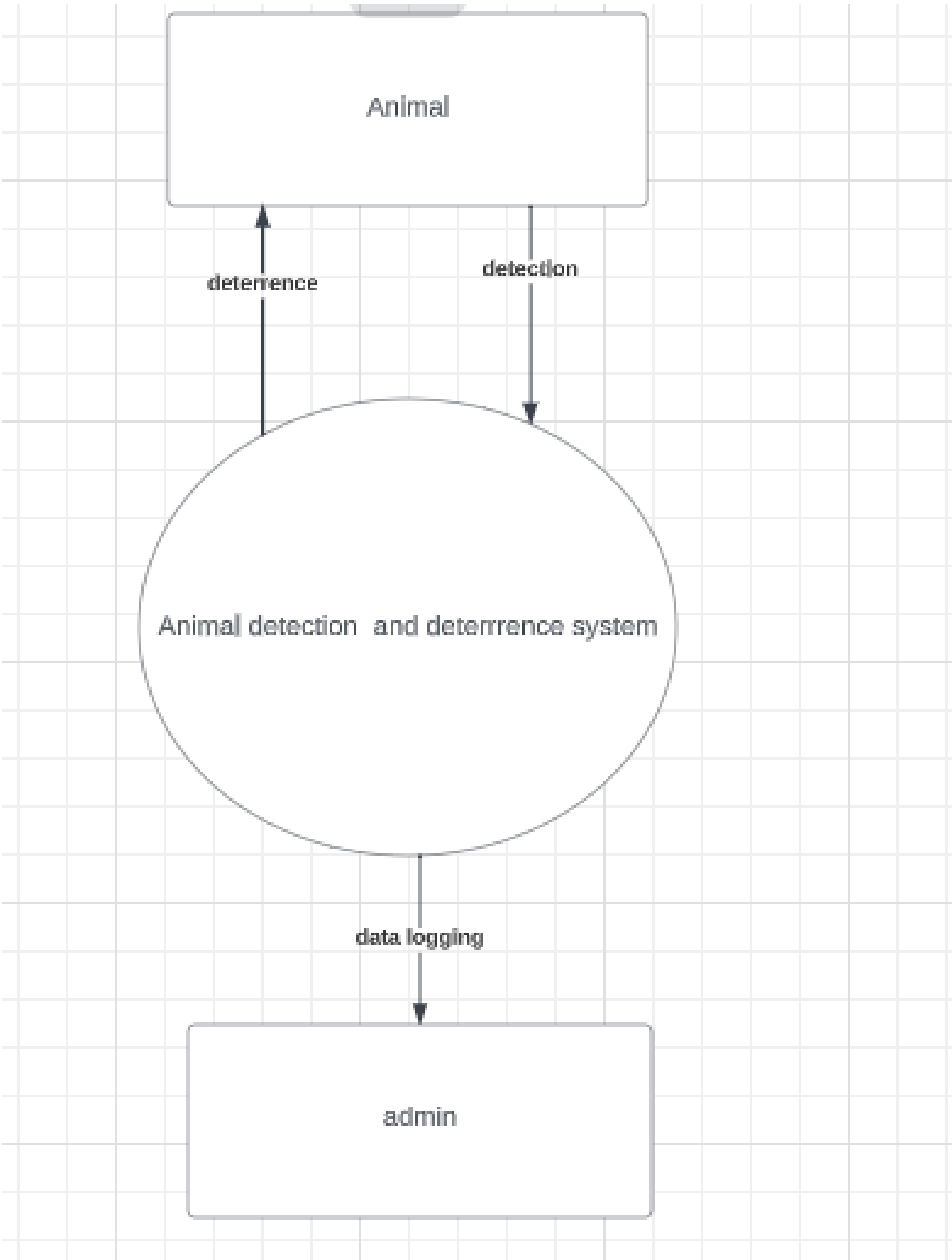

figure 3. 2 Context Diagram (Author, 2024)

Flowchart

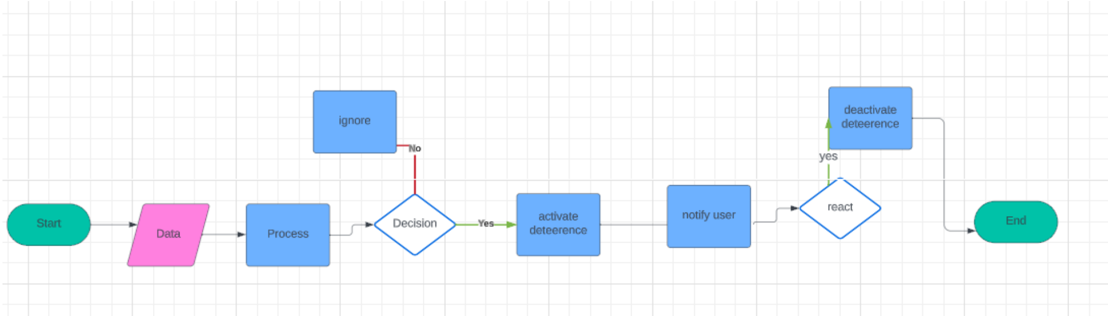

figure 3. 3 Flowchart for Current System (author, 2024)

3.6 Methodology for System Implementation; Backend, Frontend and Database Technologies to be Used

System implementation, defined as the process of transforming a system design into a functional reality, encompasses several critical stages (Pressman, 2022). This multifaceted journey begins with coding components based on established specifications (Moe et al., 2011), followed by the meticulous installation of necessary hardware and software infrastructure. The system then undergoes a rigorous configuration process to ensure optimal parameter settings and seamless integration of various components (Kerzner, 2019). Finally, comprehensive testing and validation are conducted to verify functionality and performance against established requirements.

Several key considerations influence the success of system implementation, including clearly defined requirements and appropriate technology selection. Effective project management, proactive risk identification and mitigation, and clear communication and collaboration among all stakeholders are also crucial for navigating the implementation journey (Moe et al., 2011). Additionally, the availability of technical expertise, strong project management skills, and active stakeholder engagement are vital for overcoming unforeseen challenges and achieving desired outcomes (Pressman, 2022). Ultimately, the success of system implementation hinges on a well-defined methodology, meticulous execution, and the ability to adapt to changing circumstances.

3.6.1 Back-end Technologies

The back-end of the system will be primarily built upon Python, leveraging its versatility and vast ecosystem of libraries for AI and machine learning applications. This choice enables efficient development, integration, and deployment of various system functionalities.

The key back-end components and technologies include: python3.12 for developing and deploying deep learning models for animal detection and classification. This tool offers powerful tools and pre-trained models that can be fine-tuned for the specific needs of the system. Computer Vision and Image Processing: python will be utilized for pre-processing sensor data, particularly images captured by cameras. This includes tasks like image scaling, noise reduction, and feature extraction. Machine Learning and Classification: it will also play a crucial role in building and evaluating machine learning models for animal classification based on the extracted features.

API Development: A robust API will be developed using python, serving as the interface for communication between the front-end application and the back-end services. The API will handle data exchange, including animal detection alerts, system status updates, and user commands. Arduino Integration: The system will integrate with Arduino microcontrollers to control connected devices, including cameras, sensors, and deterrence mechanisms. Python will be used for communication and control of these devices through the Arduino platform. Security and Authentication: Secure authentication and authorization protocols will be implemented to ensure system access only for authorized users. Data encryption will be employed to protect sensitive data during transmission and storage.

3.6.2 Front-end Technologies

The front-end of the system will be a mobile application primarily developed in java, tailored for Android and iOS platforms. This choice is driven by the need for a native mobile experience, ensuring optimal performance and smooth user interaction. Kotlin's concise syntax and interoperability with Java offer a familiar and efficient development environment for Android developers

The mobile application will deliver a robust and user-friendly experience.

Alerts and notifications: The application will provide immediate alerts to farmers upon animal detection, notifying them about the type of animal, its location, and the activated deterrence mechanisms. System management: The application will allow farmers to manage system settings, including adjusting sensitivity thresholds, customizing deterrence responses, and reviewing system logs. Interactive interface: The application will provide an intuitive and user-friendly interface for easy navigation and interaction with the system's features.

3.6.3 Database Technologies

The back-end of the system will heavily rely on a robust database technology to store and manage various types of data generated during operation. The chosen technology will need to handle: camera data: This includes raw data collected from sensors, such as camera images, motion detection triggers, and environmental parameters. Animal detection results: This data consists of information about detected animals, including their type, location, timestamp, and confidence score. System performance data: This includes metrics like response time, resource utilization, and overall system health. User information: This includes user accounts, login credentials, and system settings preferences. Considering these requirements, the primary database technology for the back-end will be SQLite3. This open-source relational database management system offers numerous advantages for the project: Scalability: SQLite3 can efficiently handle large datasets and high data volumes, ensuring smooth operation even as the system scales. Performance: The database delivers high performance in terms of read/write operations and data retrieval, crucial for real-time data processing and analysis.

Security: SQLite3 provides robust security features, including user authentication, authorization, and data encryption, safeguarding sensitive information. SQL support: The familiar and widely used SQL language facilitates data querying, analysis, and manipulation, allowing for flexible data management. Integration: SQLite3 integrates seamlessly with various programming languages, including Python, enabling seamless interaction with the back-end system components.

Additionally, NoSQL databases like MongoDB or Cassandra could be considered for specific functionalities. For example, MongoDB's flexible document structure might be suitable for storing unstructured sensor data like images, while Cassandra's distributed architecture could offer high availability and scalability for storing large volumes of animal detection results.

The choice of additional database technologies will depend on the specific needs of the system and the performance requirements of individual components. Ultimately, a hybrid approach utilizing both SQLite3 and other NoSQL databases could be implemented to optimize the system's data management capabilities. This would allow for the efficient handling of both structured and unstructured data, ensuring optimal performance and scalability for the entire system.

3.7 Methodology for System Testing; Testing plan, Testing techniques.

3.7.1 Methodology for System Testing

System testing, a critical stage in software development, ensures that the fully integrated system functions as intended and meets user expectations (Pressman, 2022). Conducted after successful unit and integration testing, it focuses on the system's overall behavior and its ability to fulfill user needs through interactions with external entities. The methodology for effective system testing involves a meticulous process. First, a comprehensive test plan is developed, outlining the scope, objectives, and individual test cases with expected results and success criteria (Moe et al., 2011). Test case design utilizes various techniques, such as equivalence partitioning and boundary-value analysis, to cover diverse functionalities and scenarios. A dedicated testing environment replicates the production environment as closely as possible, ensuring accurate and reliable test execution.

Systematic test execution involves comparing actual results with expected outcomes, documenting any deviations as defects for developer resolution. Comprehensive test reports summarize results, identified defects, and overall system performance, informing stakeholders and providing valuable insights for further development and improvement. System testing employs various techniques to address different aspects of functionality and performance. Black-box testing focuses on functionality without considering internal structure, using test cases to verify behavior against requirements. White-box testing leverages knowledge of the internal design to develop targeted test cases for critical components and code paths. Performance testing evaluates responsiveness, stability, and scalability under different loads. Security testing identifies and mitigates potential vulnerabilities, while usability testing assesses ease of use, learnability, and overall user experience.

Through a meticulous and comprehensive approach to system testing, we ensure the delivered system is not only functional but also secure, performant, and user-friendly, ultimately fulfilling its intended purpose and exceeding user expectations.

3.8: Methodology for System Deployment

System deployment, a critical stage in the software development lifecycle, transitions a developed system into operational use and transfers support and maintenance responsibilities to a designated organization (Sommerville, 2021). This process may involve reliability testing and phasing out legacy systems. Several key fundamentals underpin successful deployment, including meticulous transition management (Pressman & Maxim, 2015), efficient support and maintenance handover (Moe, Larson, & Hallowell, 2011), thorough performance evaluation (Sommerville, 2021), and comprehensive user training and certification (Sommerville, 2021).

Various deployment methodologies exist, each with its own advantages and disadvantages. Waterfall offers a structured approach but can be inflexible (Pressman & Maxim, 2015). Agile provides more flexibility but can be challenging to manage (Highsmith, 2009). DevOps automates deployments, requiring a cultural shift and significant investment (Humble & Farley, 2010). Choosing the best approach depends on factors like project size, complexity, and budget. Automated and manual software package creation are two primary approaches for distributing and installing software on user machines (Microsoft, 2023). Automated creation utilizes templates for quick and efficient deployment, while manual creation offers greater control over package content but can be time-consuming and error-prone. The most appropriate method depends on the complexity of the software application.

A successful deployment strategy requires careful consideration of factors like schedule, pre-deployment settings, user notifications, and reboot policy. To ensure a smooth and successful system deployment, it's crucial to: identify the optimal deployment methodology (Pressman & Maxim, 2015; Highsmith, 2009; Humble & Farley, 2010), develop a detailed deployment plan, thoroughly test the system in a pre-production environment, provide comprehensive user training (Sommerville, 2021) and continuously monitor system performance and address any issues promptly (Sommerville, 2021).

System deployment is a crucial phase in the development lifecycle, marking the transition of the Intelligent Animal Repelling System from development to operational use. This phase involves transferring the capability to end-users and managing support and maintenance responsibilities. The deployment strategy is influenced by agile principles, emphasizing iterative and collaborative approaches to ensure operational acceptability and efficiency. The deployment process begins with meticulous planning, considering factors like reliability demonstration tests and the phasing out of legacy systems. Continuous consideration for deployment and use is woven throughout the system lifecycle, recognizing that the use stage significantly impacts the overall cost and performance. The activities in this phase are managed to assess system performance, effectiveness, and cost within the intended environment over the lifecycle.

The deployment fundamentals encompass planning and managing the transition of the system into operational use, ensuring seamless integration into the existing infrastructure. Training and certification of personnel for system use are critical components during this stage. For software deployment, an agile approach is employed, involving coding, building, testing, packaging, releasing, configuring, and monitoring. The deployment methods leverage automated and manual software package creation. Manual creation allows the packaging of custom software for installation on client machines.

Choosing the right software deployment strategy is pivotal for minimal interference among end-users. This involves setting schedules, applying pre-deployment settings, notifying users before deployment, and implementing a reboot policy based on software requirements. The agile methodology is adopted to enhance flexibility, responsiveness, and collaboration throughout the deployment process, aligning with the dynamic nature of the Intelligent Animal Repelling System's development and utilization.

3.9 Chapter Summary

Chapter 3 establishes a firm foundation in research methodology, guiding researchers through the essential steps of conducting rigorous and ethical studies. It emphasizes the importance of methodology for conducting a thorough literature review, establishing a strong theoretical framework, and selecting the most appropriate methodology and data collection methods. The chapter further explores key concepts like quantitative and qualitative research approaches, data analysis, and responsible research ethics. By providing a roadmap for each stage of the research process, Chapter 3 empowers researchers to contribute meaningfully to their field with impactful and reliable findings.

CHAPTER FOUR

System Analysis

4.1 Introduction.

System Analysis delves into a comprehensive examination of the current systems relevant to the project. This chapter serves as a critical bridge between understanding existing methodologies and laying the groundwork for proposed system enhancements. By conducting a thorough analysis of the current systems, their strengths, weaknesses, and overall feasibility, this chapter sets the stage for informed decision-making in subsequent development phases. The chapter begins with an introduction that outlines its objectives and significance within the broader scope of the project. Following this, a detailed description of the current systems is provided, accompanied by an assessment of their strengths and weaknesses. This evaluation not only sheds light on existing practices but also identifies areas ripe for improvement and innovation. A feasibility study is then conducted to assess the practicality and viability of proposed system enhancements. This includes an exploration of technical, economic, and operational feasibility factors, culminating in a conclusive determination regarding the project's feasibility.

Data I/O analysis forms a crucial component of this chapter, offering insights into the data captured by the current system, the relationships between different data elements, and the outputs generated by the system. This analysis provides a deeper understanding of the information flow within the existing systems and lays the groundwork for optimizing data management strategies in the proposed system. Furthermore, the chapter explores the process logic design of the current system through the use of flowcharts, context diagrams, and Data Flow Diagrams (DFDs). These visual representations offer a structured overview of the system's operational logic, facilitating a systematic assessment of its functionality and identifying potential areas for refinement.

Finally, the chapter concludes with a summary that encapsulates the key findings and insights derived from the system analysis. This summary serves as a roadmap for the subsequent chapters, guiding the reader through the project's progression and highlighting areas of focus for the system design and implementation phases.

4.2 Description of the Current Systems

The Intelligent Animal Repelling System represents a pioneering approach in utilizing cutting-edge technology to address the persistent challenge of protecting agricultural crops from ungulate intrusion (Haakstad, 2021). By amalgamating sophisticated hardware and software elements, the system endeavors to detect and deter animals such as deer and wild boars effectively. At its core, the system harnesses the power of edge computing, employing devices like Raspberry Pi and NVIDIA Jetson Nano to execute real-time object detection algorithms (Haakstad, 2021). These algorithms, exemplified by YOLO and Tiny-YOLO, are not only capable of swift identification but also adaptable through custom-trained models tailored to discern specific animal species. Once an intruding animal is detected, the system promptly activates an ultrasound generator, emitting deterrent signals to drive them away from the crops (Haakstad, 2021). Through this intricate integration of technology and functionality, the Intelligent Animal Repelling System stands as a testament to innovation in the agricultural sector, offering a promising solution to mitigate the detrimental impact of wildlife on crop yields.

4.2.1 Strengths of the Current System

The first is real-time detection. The hallmark of the Intelligent Animal Repelling System lies in its ability to detect ungulates in real-time, enabling swift and proactive responses to potential threats against agricultural crops (Haakstad, 2021). By leveraging advanced object detection algorithms and edge computing capabilities, the system can identify intruding animals as soon as they enter the monitored area. This real-time detection feature ensures that farmers and agronomists receive immediate alerts, allowing them to take timely action to protect their crops from damage. Followed by Edge-AI Integration, a key strength of the system is its seamless integration of edge-AI technology, which empowers it to perform complex computational tasks locally on edge devices. By deploying edge computing resources such as Raspberry Pi and NVIDIA Jetson Nano, the system can execute sophisticated object detection algorithms without relying on centralized servers or cloud infrastructure. This integration not only minimizes latency but also enhances the system's efficiency and responsiveness, making it well-suited for deployment in remote agricultural settings where network connectivity may be limited (Haakstad, 2021).

The solution’s is cost-effectiveness. The Intelligent Animal Repelling System offers a cost-effective solution for crop protection in agriculture, particularly in rural areas with limited resources (Haakstad, 2021). By leveraging low-power edge computing devices and open-source software frameworks, the system significantly reduces the upfront and operational costs associated with deploying advanced technology solutions. This affordability makes the system accessible to small-scale farmers and agricultural communities, democratizing access to innovative tools for crop management and protection.

Its customization as an added advantage. Another notable strength of the system is its inherent flexibility and customization capabilities. Farmers and agronomists can tailor the system's animal recognition models to suit the specific needs and challenges of their agricultural environments. By training custom models with localized data, users can enhance the system's accuracy and adaptability to different wildlife species and crop configurations (Haakstad, 2021). This customization empowers stakeholders to fine-tune the system according to evolving threats and environmental conditions, maximizing its effectiveness in protecting crops.

The system is energy efficiency. The system is designed with energy efficiency in mind, minimizing power consumption while maintaining optimal performance. By leveraging low-power edge computing devices and optimizing algorithmic processes, the system operates efficiently even in resource-constrained environments (Haakstad, 2021). This energy efficiency not only reduces operational costs but also minimizes the environmental footprint of the system, aligning with sustainable practices in modern agriculture. As a result, the Intelligent Animal Repelling System offers a scalable and environmentally conscious solution for crop protection.

4.2.2 Weaknesses of the Current System

The system has limited coverage. Despite its real-time detection capabilities, one of the primary weaknesses of the Intelligent Animal Repelling System is its limited coverage area. The effectiveness of the system in deterring ungulates from agricultural fields may be constrained by the range of the ultrasound generator used for repelling animals (Haakstad, 2021). In larger agricultural settings or expansive farm areas, the coverage provided by a single ultrasound emitter may not suffice to protect crops comprehensively. As a result, certain regions within the monitored area may remain vulnerable to animal intrusions, potentially undermining the overall efficacy of the system.

The system has daunting maintenance requirements. Another challenge associated with the current system relates to its maintenance requirements. While the system offers advanced functionalities for crop protection, it also necessitates regular maintenance and monitoring to ensure continuous operation. Components such as edge computing devices, sensors, and the ultrasound generator may require periodic inspection, calibration, and servicing to uphold their functionality and performance standards. Failure to address maintenance needs adequately could lead to system malfunctions or downtime, compromising the system's reliability and effectiveness in safeguarding agricultural crops (Haakstad, 2021).

Training Data Dependencies. The accuracy and efficacy of the Intelligent Animal Repelling System heavily rely on the quality and quantity of training data used to develop its animal recognition models (Haakstad, 2021). Inadequate or insufficient training data may result in suboptimal performance and false positives or negatives during animal detection. Moreover, the dynamic nature of wildlife behavior and environmental conditions necessitates ongoing updates and improvements to the training dataset to ensure the system's adaptability and reliability over time. Consequently, the system's dependence on high-quality training data poses a significant challenge for its long-term effectiveness and sustainability in real-world agricultural settings.

Connectivity Challenges. Connectivity issues pose a significant hurdle to the seamless operation of the Intelligent Animal Repelling System, particularly in rural agricultural environments with limited network infrastructure. In areas with poor cellular reception or unreliable internet connectivity, the system may encounter difficulties in transmitting real-time data, receiving software updates, or accessing cloud-based services for remote monitoring and management. Such connectivity challenges can impede the system's responsiveness and hinder timely interventions in the event of animal intrusions, potentially compromising crop protection efforts and exacerbating losses for farmers.

4.3 Feasibility Study

The feasibility study for the Intelligent Animal Repelling System for Crop Protection based on Embedded Edge-AI delves into several critical aspects to determine the system's viability and practicality in real-world agricultural scenarios (Haakstad, 2021). Through a thorough examination of technical, economic, and operational factors, the study aims to provide insights into the system's feasibility and potential benefits for agricultural stakeholders (Haakstad, 2021).

The technical feasibility assessment focuses on evaluating the system's ability to perform its intended functions effectively and efficiently. This involves analyzing the capabilities of the edge computing devices, such as Raspberry Pi and NVIDIA Jetson Nano, to execute real-time object detection algorithms (Haakstad, 2021). The performance of these algorithms, particularly YOLO and Tiny-YOLO with custom-trained models, is scrutinized to ensure accurate and timely detection of ungulates in agricultural fields. Additionally, the effectiveness of the ultrasound generator in repelling animals is evaluated to ascertain its reliability in deterring potential threats to crops (Haakstad, 2021). Through rigorous testing and analysis, the feasibility study aims to determine whether the system can consistently deliver the desired outcomes under varying environmental conditions and operational scenarios.

In assessing the economic feasibility of the system, the feasibility study examines the costs associated with deploying, operating, and maintaining the technology in agricultural settings. This includes evaluating the initial investment required for procuring hardware components, software licenses, and training personnel. Moreover, the study considers ongoing operational expenses, such as energy consumption, maintenance, and updates, to gauge the long-term affordability of the system (Haakstad, 2021). By comparing the projected costs and benefits over the system's lifecycle, the feasibility study aims to determine the economic viability of implementing the Intelligent Animal Repelling System and its potential return on investment for farmers and agronomists.

Operational feasibility assesses the practicality and usability of the system within the context of agricultural operations. This involves evaluating factors such as ease of deployment, user-friendliness of the interface, and compatibility with existing farm practices (Haakstad, 2021). The feasibility study examines the system's integration with farm infrastructure, workflows, and personnel training requirements to identify any potential challenges or barriers to adoption. Additionally, considerations are made regarding the system's scalability, adaptability to different agricultural environments, and ability to withstand environmental factors such as weather conditions and terrain variations (Haakstad, 2021). By addressing these operational aspects, the feasibility study aims to ensure that the Intelligent Animal Repelling System can be seamlessly integrated into farm operations and effectively contribute to crop protection efforts.

4.4 Conclusion of the Feasibility Study

In conclusion, the feasibility study provides valuable insights into the technical, economic, and operational feasibility of the Intelligent Animal Repelling System for Crop Protection based on Embedded Edge-AI. By demonstrating strong technical capabilities, promising economic returns, and practical usability in agricultural settings, the system emerges as a viable solution for enhancing crop protection and mitigating the impact of ungulate attacks on agricultural productivity. With careful consideration of the study's findings and recommendations, stakeholders can make informed decisions regarding the implementation and deployment of the system, paving the way for sustainable and efficient agricultural practices.

4.5 Process Logic Design of the Current System; Flow Charts, Context Diagrams & DFDS

DFD

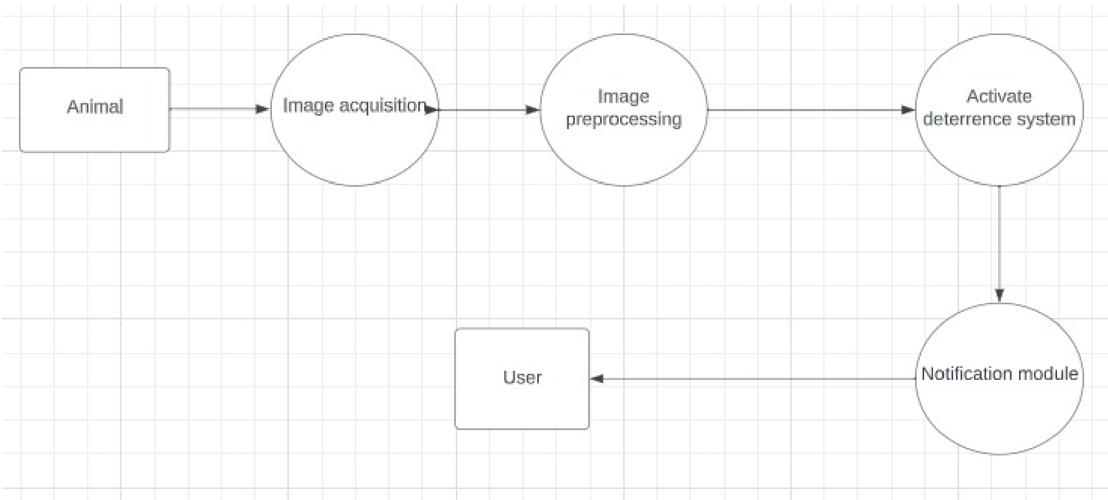

figure 4. 1 A Data Flow Diagram for The Current System (Author, 2024)

Context Diagram:

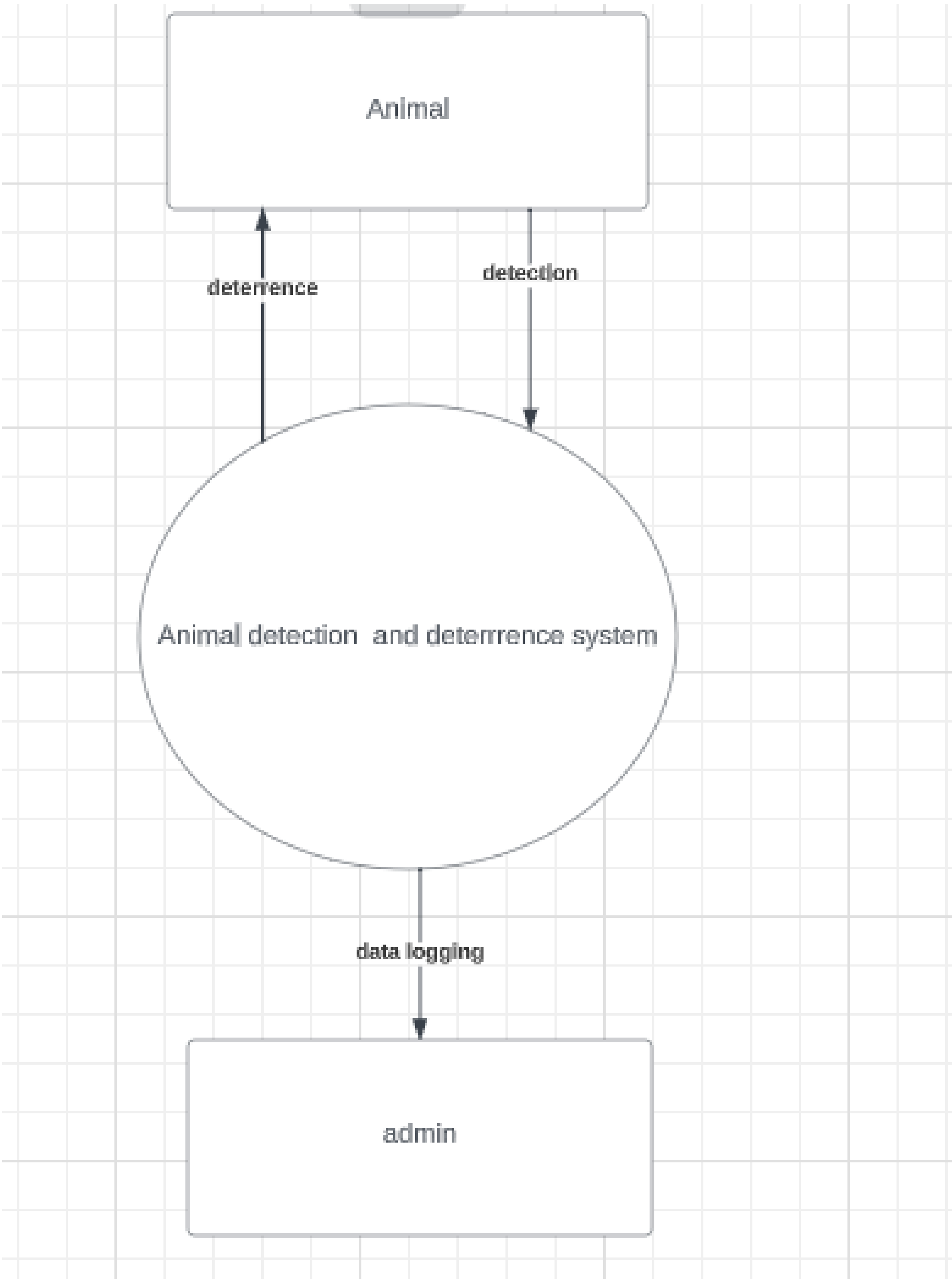

figure 4. 2 Context Flow Diagram for The Current (Author, 2024)

Flowchart

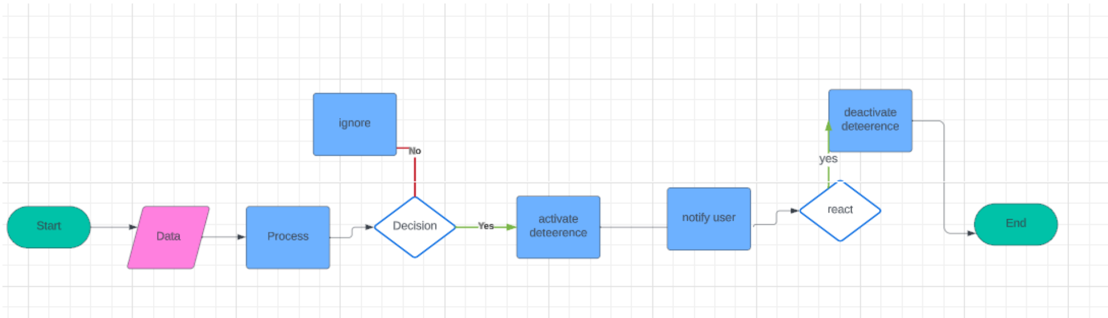

figure 4. 3 Flowchart for The Current System (Author, 2024)

4.6 Chapter Summary

In this chapter, a comprehensive analysis of the current irrigation systems has been provided, revealing a diverse range of methods employed in the study area, from traditional manual approaches to modern automated systems. The strengths of the current systems, including familiarity, low initial costs, and local adaptability, were highlighted, alongside identified weaknesses such as water wastage, labor intensity, and limited precision. A thorough feasibility study assessed the viability of implementing the proposed Arduino-Based Automatic Irrigation System, indicating strong potential for addressing challenges sustainably and cost-effectively. The data I/O analysis underscored the complexities of managing irrigation practices, while process logic design visuals depicted the current system's workflow. This chapter sets the groundwork for subsequent discussions on the proposed system, aiming to enhance the efficiency and sustainability of smallholder farming practices.

CHAPTER FIVE

System Design

5.1 Introduction

In this chapter, the research delves into the intricacies of designing the proposed Intelligent Animal Repelling System. This chapter comprehensively covers various aspects of system design, including conceptual architecture, requirement analysis, process logic, database design, and user interface. The exploration focuses on how the integration of IoT technology and AI capabilities forms the foundation of the system, enabling effective elephant detection and deterrence in agricultural fields. The details of each component are examined to understand their contributions to the functionality and usability of the proposed system.

5.2 Description of the Proposed Systems

This system amalgamates IoT components with AI-driven image processing algorithms to detect and deter elephants effectively, safeguarding crops from potential damage. At its core, the system comprises hardware elements such as Arduino microcontrollers, Wi-Fi modules, buzzers, breadboards, and cameras, synchronized to capture periodic images of the agricultural terrain. These images serve as input data for the Django-based web server, functioning as the central processing unit. Here, an AI model is employed to meticulously analyze the images, employing sophisticated image processing techniques and machine learning algorithms to discern the presence of elephants accurately.

In operation, the proposed system follows a streamlined workflow: cameras installed across the agricultural expanse capture images at predefined intervals, which are promptly transmitted to the Django server via the Wi-Fi module. Upon reception, the server initiates the AI model to scrutinize the images, meticulously scanning for signs of elephant presence. Upon detection, the system swiftly triggers the buzzer remotely, aiming to deter the intruding elephants and safeguard the crops. Moreover, instant alerts are dispatched to farmers, notifying them of the intrusion and enabling timely intervention. This proactive approach underscores the system's efficacy in mitigating crop losses attributable to elephant incursions, fostering a sustainable agricultural ecosystem.

While the proposed system boasts several strengths, including real-time monitoring capabilities and AI-driven precision in elephant detection, it is not devoid of limitations. Challenges such as restricted coverage due to camera placement and potential connectivity issues in remote agricultural locales may impede its seamless operation. Nonetheless, the system's value proposition lies in its ability to furnish farmers with an innovative, technology-driven solution to counteract the pervasive threat of elephant-induced crop damage. By leveraging the synergy of IoT and AI, it offers a pragmatic pathway towards bolstering agricultural resilience and fortifying crop protection measures against the backdrop of wildlife incursions.

5.2.1 Strengths the Proposed Systems

The proposed Intelligent Animal Repelling System offers a comprehensive solution to the pervasive challenge of elephant incursions in agricultural landscapes, fortified by an array of robust features and capabilities. At its core, the system's real-time monitoring capabilities stand as a testament to its efficacy, providing farmers with timely insights into elephant activity within their fields. Leveraging IoT technology and Wi-Fi connectivity, the system meticulously captures images at predefined intervals, ensuring prompt detection of elephant presence and facilitating proactive intervention to safeguard crops. This real-time monitoring not only enhances farmers' situational awareness but also empowers them to implement preemptive measures, minimizing the risk of crop damage and maximizing agricultural productivity.

A key distinguishing factor of the proposed system lies in its precision in elephant detection, underpinned by an advanced AI-driven image processing algorithm. Through meticulous training and optimization, the algorithm exhibits unparalleled accuracy in discerning elephants amidst agricultural terrain, significantly reducing false positives and ensuring reliable identification of intruding animals. By harnessing the power of machine learning, the system enhances its ability to differentiate elephants from other environmental elements, such as trees or vegetation, thereby bolstering its effectiveness in mitigating crop losses caused by wildlife incursions.

Furthermore, the system's capability to remotely activate deterrent measures represents a paradigm shift in crop protection strategies, affording farmers unprecedented control over wildlife interactions in their fields. Seamlessly integrated with IoT components like Arduino microcontrollers and buzzers, the system can trigger deterrent signals in real-time upon detecting elephant presence, effectively deterring animals and preventing crop damage. This remote activation feature not only minimizes the need for physical intervention but also enables swift and decisive responses to potential threats, thereby safeguarding agricultural yields and preserving farmer livelihoods.

In addition to its proactive deterrent measures, the system incorporates a robust alerting mechanism designed to promptly notify farmers of elephant activity in their fields. Leveraging the Django-based web server, the system delivers instant alerts to farmers, empowering them to take timely action and implement appropriate mitigation strategies. These alerts serve as a crucial early warning system, enabling farmers to deploy resources effectively and mitigate the impact of wildlife incursions on agricultural productivity. By facilitating rapid response and decision-making, the alerting mechanism enhances farmers' resilience to wildlife-related risks, fostering sustainable farming practices and ensuring long-term agricultural viability.

5.2.2 Weaknesses the Proposed Systems

Despite its innovative design and promising capabilities, the proposed Intelligent

Animal Repelling System is not without its limitations and weaknesses, which merit careful consideration in the system's development and implementation. One notable weakness pertains to the system's reliance on external factors such as weather conditions and environmental variables, which can adversely affect its performance and reliability. In particular, inclement weather conditions such as heavy rainfall or dense fog may compromise the system's image capture capabilities, potentially leading to reduced detection accuracy and false negatives. Moreover, environmental factors such as foliage density and terrain topography can obscure the visibility of elephants in captured images, posing challenges to the system's effectiveness in detecting intruding animals accurately.

Another significant weakness of the proposed system lies in its susceptibility to false alarms and erroneous detections, which can undermine farmers' confidence in the system's reliability and integrity. Despite the algorithm's advanced image processing capabilities, it may occasionally misclassify environmental elements as elephants, leading to false positives and unnecessary activation of deterrent measures. These false alarms not only contribute to unnecessary disruptions and resource wastage but also erode farmers' trust in the system's efficacy, potentially diminishing its adoption and acceptance within agricultural communities.

Furthermore, the proposed system's dependence on Wi-Fi connectivity for data transmission and remote activation represents a vulnerability that may impede its functionality in remote or rural agricultural settings with limited network infrastructure. In areas plagued by connectivity issues or network outages, the system may experience delays or failures in transmitting critical data and alerts, compromising its ability to deliver timely notifications to farmers and respond effectively to wildlife incursions. This dependency on external communication channels underscores the need for alternative communication protocols or offline functionalities to ensure the system's robustness and resilience in diverse environmental conditions.

Additionally, the system's reliance on battery-powered IoT devices introduces challenges related to energy consumption and device maintenance, particularly in off-grid or resource-constrained environments. The limited battery life of IoT components may necessitate frequent battery replacements or recharging cycles, leading to increased operational costs and logistical complexities for farmers. Moreover, inadequate maintenance and monitoring of IoT devices may result in device failures or malfunctions, compromising the system's overall performance and effectiveness in mitigating wildlife incursions.

In conclusion, while the proposed Intelligent Animal Repelling System offers significant potential for enhancing crop protection and mitigating human-wildlife conflicts, its vulnerabilities and weaknesses underscore the importance of thorough testing, optimization, and ongoing refinement to address these challenges effectively. By acknowledging and mitigating these weaknesses, stakeholders can ensure the system's reliability, resilience, and suitability for deployment in real-world agricultural settings, ultimately maximizing its impact on agricultural sustainability and farmer livelihoods.

5.3 Requirement Analysis

The requirement analysis for the proposed Intelligent Animal Repelling System encompasses a comprehensive evaluation of functional, nonfunctional, user-related, and usability requirements essential for designing and implementing a robust and user-friendly solution tailored to the needs of farmers and agronomists.

5.3.1 Functional Requirements

5.3.1.1 Real-time image capture and processing

The proposed system incorporates real-time image capture capabilities, allowing for continuous monitoring of the agricultural environment. Utilizing high-resolution cameras or image sensors, the system captures images at regular intervals, ensuring up-to-date surveillance of the farm. These captured images are processed in real-time using advanced image processing algorithms, enabling rapid analysis and detection of potential intruders, including elephants and other animals. By leveraging real-time processing, the system can promptly identify and respond to threats, enhancing overall security and protection of the agricultural assets.

5.3.1.2 Automated detection of elephants

Through the integration of intelligent detection algorithms, the system autonomously identifies intruding elephants. Leveraging machine learning and computer vision techniques, the system learns to recognize characteristic features and behavioral patterns associated with target animals. This automated detection capability enables the system to efficiently filter out irrelevant data and focus specifically on detecting potential threats. By automating the detection process, the system minimizes the need for manual intervention, enhancing efficiency and accuracy in identifying intruding animals.

5.3.1.3 Remote activation of deterrent measures

As a proactive measure to deter intruding animals, the system facilitates remote activation of deterrent devices, such as buzzers, through a web-based interface. Upon detecting the presence of elephants or other animals, the system triggers the activation of deterrent measures, emitting audible signals to discourage further intrusion. This remote activation capability provides farmers with a convenient means of responding to threats in real-time, even when they are not physically present on the farm. By enabling remote control of deterrent measures, the system empowers farmers to take immediate action to protect their crops and minimize potential damage.

5.3.1.4 Generation of alerts and notifications to farmers

The proposed system includes functionality for generating alerts and notifications to farmers in response to detected intrusions. Upon identifying the presence of elephants or other intruding animals, the system initiates the transmission of alerts to designated farmer recipients via various communication channels, through email notifications. These alerts promptly inform farmers of potential threats, allowing them to take timely action to mitigate risks and safeguard their agricultural assets. By providing real-time notifications, the system enhances situational awareness and enables proactive decision-making, ultimately contributing to improved farm security and management.

5.3.1.5 Seamless integration with the web-based user interface for remote control

To facilitate ease of use and accessibility, the proposed system seamlessly integrates with a web-based user interface, enabling remote control and monitoring functionalities. Through the user interface, farmers can remotely access and manage the system from any internet-connected device, such as smartphones, tablets, or computers. The interface provides intuitive controls for configuring system settings, viewing real-time status updates, and responding to detected threats. This seamless integration empowers farmers with remote visibility and control over their agricultural security operations, enhancing convenience, flexibility, and overall system usability.

5.3.2 Non-functional Requirements

5.3.2.1 High detection accuracy (>90%)

The nonfunctional requirement for high detection accuracy (>90%) emphasizes the system's capability to minimize false alarms and ensure reliable identification of intruding animals. Achieving high accuracy is crucial for instilling confidence in the system's performance and minimizing the risk of false positives, which could lead to unnecessary disruptions or alarm fatigue for users. By setting a threshold of 90% accuracy, the system aims to maintain a high level of precision in animal detection, thereby enhancing its effectiveness in protecting agricultural crops and minimizing the likelihood of missed intrusions.

5.3.2.2 Low latency in alert generation and response

The nonfunctional requirement for low latency in alert generation and response underscores the importance of timely notification and intervention in response to detected intrusions. Minimizing latency ensures that alerts are promptly generated and transmitted to users upon the detection of intruding animals, enabling swift decision-making and action. With a latency target of less than a few seconds, the system aims to provide near-real-time responsiveness, enhancing its ability to support proactive crop protection measures and mitigate potential risks effectively.

5.3.2.3 Robust security measures

The nonfunctional requirement for robust security measures emphasizes the importance of safeguarding data integrity and privacy within the system. To address this requirement, the system implements robust security protocols such as encryption and authentication to protect sensitive information from unauthorized access or tampering. By prioritizing security, the system ensures that data exchanged between components and users remains confidential and secure, mitigating the risk of data breaches or malicious activities that could compromise system integrity or user privacy.

5.3.2.4 Scalability to accommodate varying farm sizes and environmental conditions

The nonfunctional requirement for scalability highlights the system's ability to adapt and scale to accommodate varying farm sizes and environmental conditions. Scalability ensures that the system can effectively serve farms of different scales, from small family-owned operations to large commercial enterprises, without compromising performance or functionality. By designing the system to be scalable, the researcher ensures that it can flexibly adjust to evolving agricultural needs and environmental factors, providing farmers with a versatile and adaptable solution for crop protection management.

5.3.2.5 Ease of maintenance to ensure ongoing system reliability and operability

The nonfunctional requirement for ease of maintenance emphasizes the importance of ensuring ongoing system reliability and operability through simplified maintenance procedures. By prioritizing ease of maintenance, the system minimizes downtime and disruption caused by maintenance activities, enabling uninterrupted operation and timely response to detected intrusions. Through streamlined maintenance processes and intuitive user interfaces, the system aims to empower users with the tools and resources needed to effectively manage and maintain system integrity, ensuring sustained performance and longevity over time.

5.3.3 User Requirements

5.3.3.1 Intuitive and user-friendly interfaces for system configuration and control

User requirements dictate the need for intuitive and user-friendly interfaces that facilitate effortless system configuration and control (Neil, 2008). The interfaces should be designed with usability in mind, employing clear layouts, intuitive navigation, and easily understandable controls to streamline user interactions. By prioritizing user-friendliness, the system aims to empower users with the ability to configure and control system settings efficiently, minimizing the learning curve and enhancing overall user satisfaction.

5.3.3.2 Customizable alert settings (e.g., notification preferences, frequency)

User requirements include customizable alert settings that enable users to tailor notification preferences and frequency according to their specific needs and preferences (Neil, 2008). The system should offer flexibility in configuring alert parameters, allowing users to choose the types of notifications they receive, the frequency of alerts, and the preferred communication channels (e.g., email, SMS). By providing customizable alert settings, the system enhances user control and responsiveness, ensuring that users receive timely and relevant notifications without being overwhelmed by unnecessary alerts.

5.3.3.3 Real-time feedback on system status and performance

User requirements mandate real-time feedback on system status and performance to keep users informed about the system's operational status and effectiveness (Neil, 2008). The system should provide comprehensive feedback on key metrics such as detection accuracy, alert responsiveness, and overall system health through intuitive dashboards or status indicators. By delivering real-time feedback, the system empowers users with actionable insights into system performance, enabling them to make informed decisions and take proactive measures to optimize system operation and maximize effectiveness.

5.3.3.4 Accessible Support Resources (e.g., User Manuals, Online Tutorials) for User Adoption and Troubleshooting

User requirements emphasize the importance of accessible support resources, such as user manuals and online tutorials, to facilitate user adoption and troubleshooting (Neil, 2008). The system should provide comprehensive documentation and guidance materials that are easily accessible and comprehensible to users of all skill levels. Additionally, the system should offer responsive customer support channels to address user inquiries and resolve issues promptly. By offering accessible support resources, the system promotes user confidence and self-sufficiency, enabling users to effectively leverage the system's capabilities and address any challenges that may arise during operation.

5.3.4 Usability Requirements

5.3.4.1 Intuitive and visually appealing user interfaces

The system prioritizes user satisfaction through intuitive and visually appealing interfaces, designed to facilitate seamless interaction (Neil, 2008). By employing user-friendly layouts and intuitive navigation menus, users can navigate the system effortlessly, enhancing their overall experience. Visual elements are thoughtfully integrated to engage users and promote ease of comprehension, ensuring a positive interaction environment. Through intuitive design principles and aesthetic considerations, the system aims to foster user engagement and satisfaction, ultimately improving usability.

5.3.4.2 Streamlined Workflows for Configuring and Managing System Settings

Efficiency is paramount in system interaction, thus the implementation of streamlined workflows for configuration and management tasks is essential (Neil, 2008). Users will encounter clear and logical pathways to access and modify settings, minimizing cognitive load and operational complexities. By optimizing workflow processes, the system enhances user productivity and confidence, enabling them to complete tasks efficiently and with ease. The emphasis on streamlined workflows underscores the system's commitment to providing hassle-free user interactions.

5.3.4.3 Clear and Concise Feedback Mechanisms (e.g., Status Indicators, Error Messages)

User actions and system status require prompt and informative feedback, facilitated through clear and concise mechanisms (Neil, 2008). Status indicators and error messages are strategically employed to communicate important information effectively, guiding users through their interactions. Visual cues and descriptive messages enhance user understanding of system behavior, promoting awareness and confidence. The implementation of clear feedback mechanisms underscores the system's commitment to facilitating smooth user experiences and minimizing misunderstandings.

5.3.4.4 Responsive Design for Multi-device Compatibility

The system prioritizes accessibility across various devices, ensuring compatibility with different platforms and screen sizes (Neil, 2008). Through responsive design principles, the system seamlessly adapts to desktops, laptops, tablets, and smartphones, preserving usability and functionality. By embracing responsive design, users can access and interact with the system from their preferred devices, enjoying optimal viewing and interaction experiences. The commitment to multi-device compatibility underscores the system's accessibility and user-centric approach.

5.3.4.5 Support for Accessibility Features to Accommodate Users with Diverse Needs

Inclusivity is a key focus of the system, as it endeavors to accommodate users with diverse needs and preferences (Alli, 2020). By supporting accessibility features in adherence to standards such as WCAG, the system ensures equal access for all users. Features like alternative text for images, keyboard navigation options, and adjustable font sizes cater to users with disabilities or special requirements, enabling effective engagement. The system's commitment to accessibility reflects its dedication to providing an inclusive and user-friendly environment for all users.

5.4 Conceptual Architecture of the Proposed System

Conceptualizing the system involves developing a high-level overview of its design, structure, and functionality without delving into specific implementation details (Alli, 2020). In the case of the proposed system for preventing elephant intrusions in farms using IoT and AI technologies, the conceptualization would involve outlining the key components and their interactions. At the core of the system is an IoT setup comprising Arduino microcontrollers, Wi-Fi modules, a buzzer, a breadboard, and a camera. These hardware components work together to capture images of farm areas at regular intervals and transmit them wirelessly to a central processing unit.

On the software side, the system incorporates AI algorithms hosted on a Django-based web server. These algorithms analyze the captured images to detect the presence of elephants or other intruding animals. Upon detection, the system triggers a response mechanism, activating the buzzer to deter the elephants and sending real-time alerts to farmers. The conceptual architecture also includes a user interface accessible through the Django website. This interface allows farmers to remotely monitor the system, view captured images, and manage alert settings. Additionally, it enables farmers to deactivate the buzzer or acknowledge alerts, providing them with control and oversight over the system's operation.

Overall, the conceptualization of the system outlines a comprehensive solution that integrates IoT devices, AI algorithms, and web-based interfaces to prevent elephant intrusions in farms effectively. By visualizing the system's components and their interactions, stakeholders can better understand its functionality and potential impact on mitigating human-wildlife conflicts.

5.5 Process Logic Design of the Proposes; Use Case, Activity Diagram, Sequence and Class Diagrams, Flow Charts, Context Diagrams, DFDS

5.5.1 Use Case Diagram

In the use case diagram, it depicts the user interacting with the system where the system is always on 24/7. Upon detection of an elephant the system sends an email alert that an elephant is approaching. The user can then power on the deterrent system.

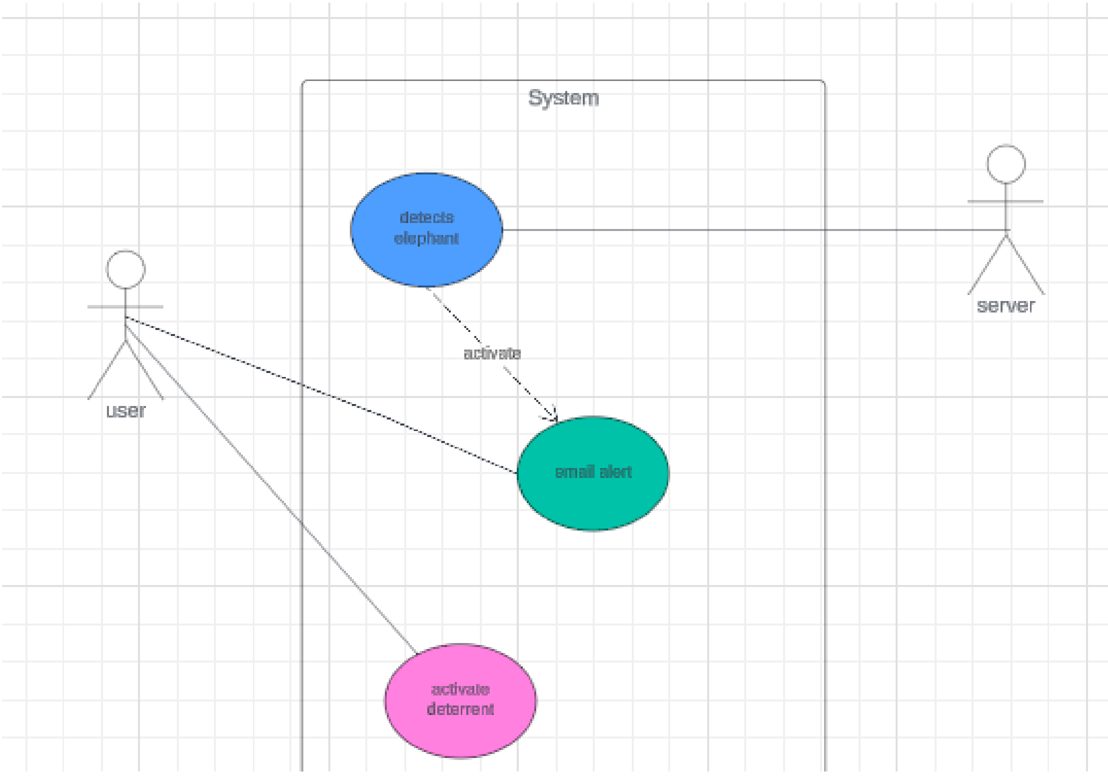

figure 5. 1 use case diagram (Author, 2024)

5.5.2 Activity diagram

Activity on how a user goes about signing in and login in

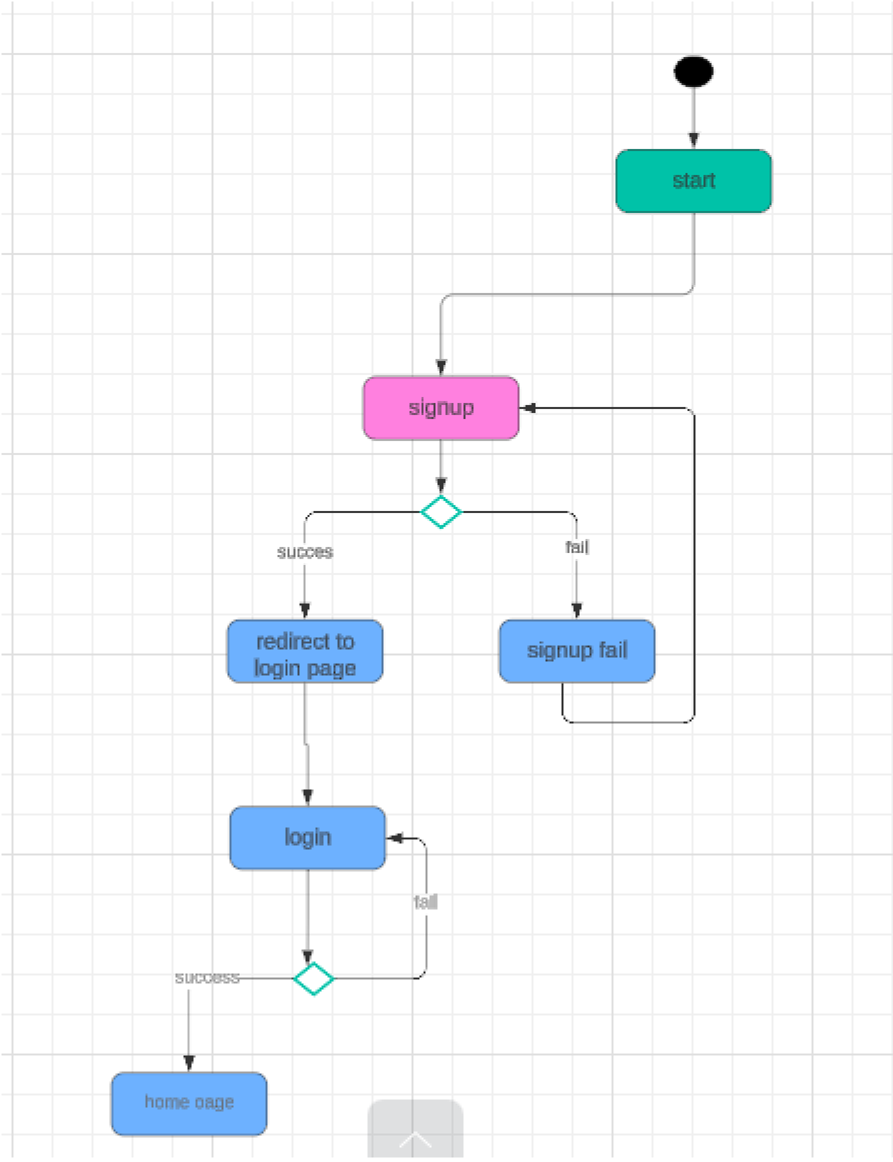

figure 5. 2 activity diagram how a user logs in or sign up (Author, 2024)

5.5.3 Context Diagram

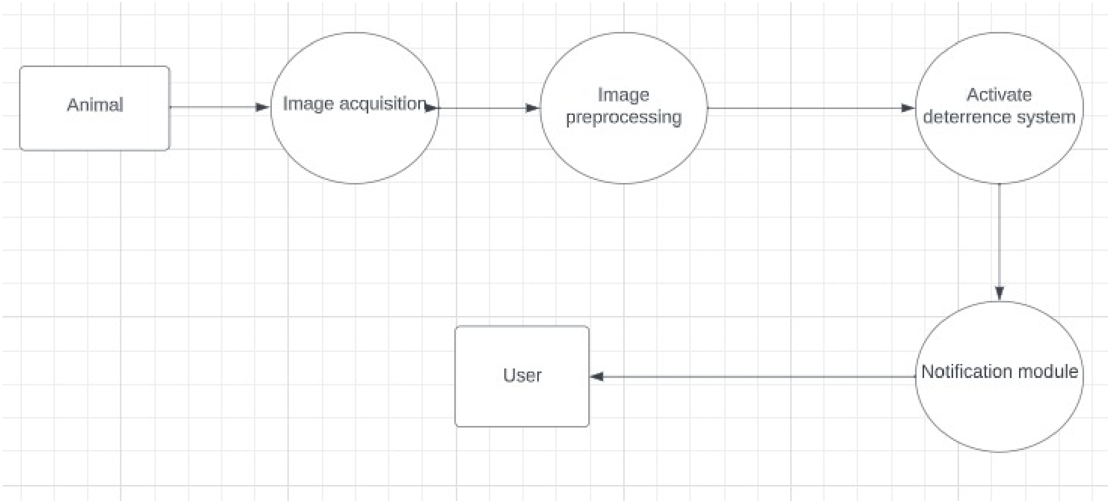

figure 5. 3 a context diagram (Author, 2024)

5.6 Database Design: ER, Normalization and Data Dictionary

5.6.1 Entity-Relationship Diagram (ERD)

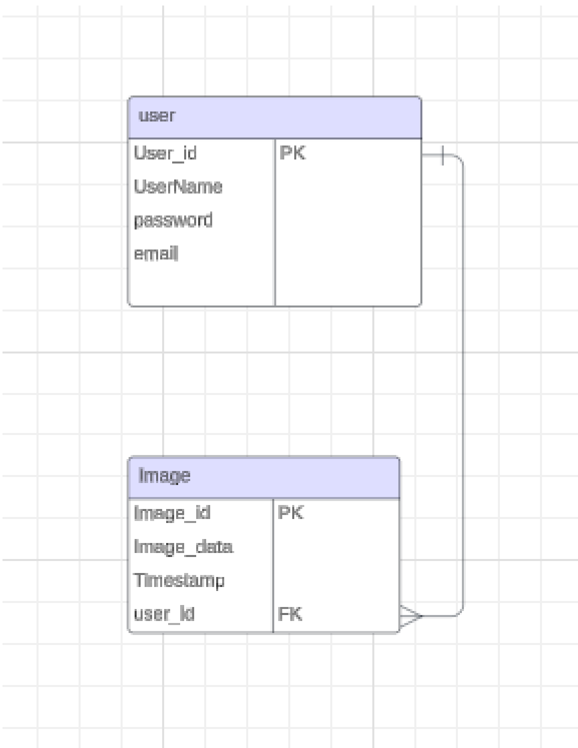

figure 5. 4 ER diagram (Author, 2024)

In this diagram:

User Table: Contains information about users.

user_id (Primary Key): Unique identifier for each user.
username: Username of the user.
password: Password of the user (hashed for security).
email: Email address of the user.

Image Table: Contains information about uploaded images.
image_id (Primary Key): Unique identifier for each image.
image_data: Data of the uploaded image.
timestamp: Timestamp indicating when the image was uploaded.
user_id (Foreign Key): References the `user_id` in the User table to establish a relationship between users and their uploaded images. Each image belongs to one user, but a user can have multiple images.

This ERD represents the database schema with a one-to-many relationship between users and images, where each user can upload multiple images, but each image belongs to only one user.

5.6.2 Normalized ER

User Table:

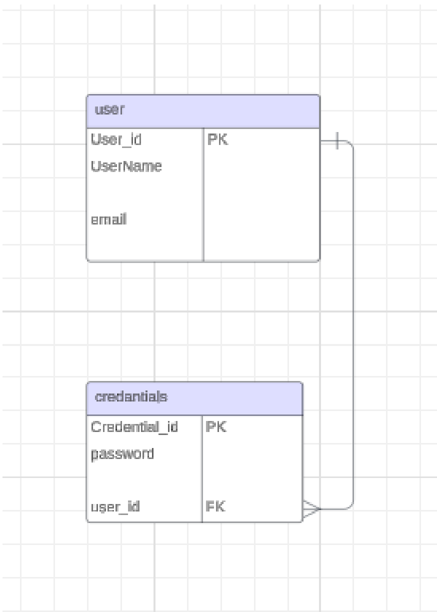

figure 5. 5 normalized user table (author, 2024)

Image Table:

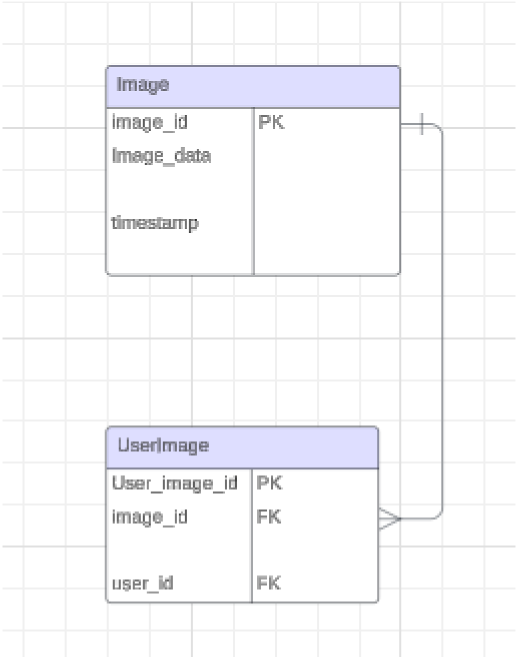

figure 5. 6 Normalized Image table (author, 2024)

In this normalized schema:

User Table: Contains information about users.

user_id (Primary Key): Unique identifier for each user.

username: Username of the user.

email: Email address of the user.

Credentials Table: Contains user credentials (password).

credential_id (Primary Key): Unique identifier for each set of credentials.

password: Password of the user (hashed for security).

Foreign Key `user_id` references the `user_id` in the User table to establish a one-to-one relationship between users and their credentials.

Image Table: Contains information about uploaded images.

image_id (Primary Key): Unique identifier for each image.

image_data: Data of the uploaded image.

timestamp: Timestamp indicating when the image was uploaded.

UserImage Table: Represents the relationship between users and their uploaded images.
user_image_id (Primary Key): Unique identifier for each user-image relationship.
Foreign Key `image_id` references the `image_id` in the Image table.
Foreign Key `user_id` references the `user_id` in the User table.

This normalized schema reduces data redundancy and ensures better data integrity by separating user credentials into a separate table and using foreign keys to establish relationships between tables.

5.6.3 Data Dictionary

User Table:
user_id: (Primary Key) Unique identifier for each user. Data type: Integer.
username: Username of the user. Data type: String.
email: Email address of the user. Data type: String.

Credentials Table:
credential_id: (Primary Key) Unique identifier for each set of credentials. Data type: Integer.
password: Password of the user (hashed for security). Data type: String.
user_id: (Foreign Key) References the `user_id` in the User table to establish a one-to-one relationship between users and their credentials. Data type: Integer.

Image Table:
image_id (Primary Key) Unique identifier for each image. Data type: Integer.
image_data: Data of the uploaded image. Data type: Binary (or any appropriate data type for storing image data).
timestamp: Timestamp indicating when the image was uploaded. Data type: Datetime or Timestamp.

UserImage Table:

user_image_id: (Primary Key) Unique identifier for each user-image relationship. Data type: Integer.

image_id: (Foreign Key) References the `image_id` in the Image table. Data type: Integer.

user_id: (Foreign Key) References the `user_id` in the User table. Data type: Integer.

This data dictionary provides a clear description of each attribute in the database schema, including the data type and any constraints such as primary keys and foreign keys.

5.7 I/O of the Proposed System (Mock Up Screens)

User starts by signing up

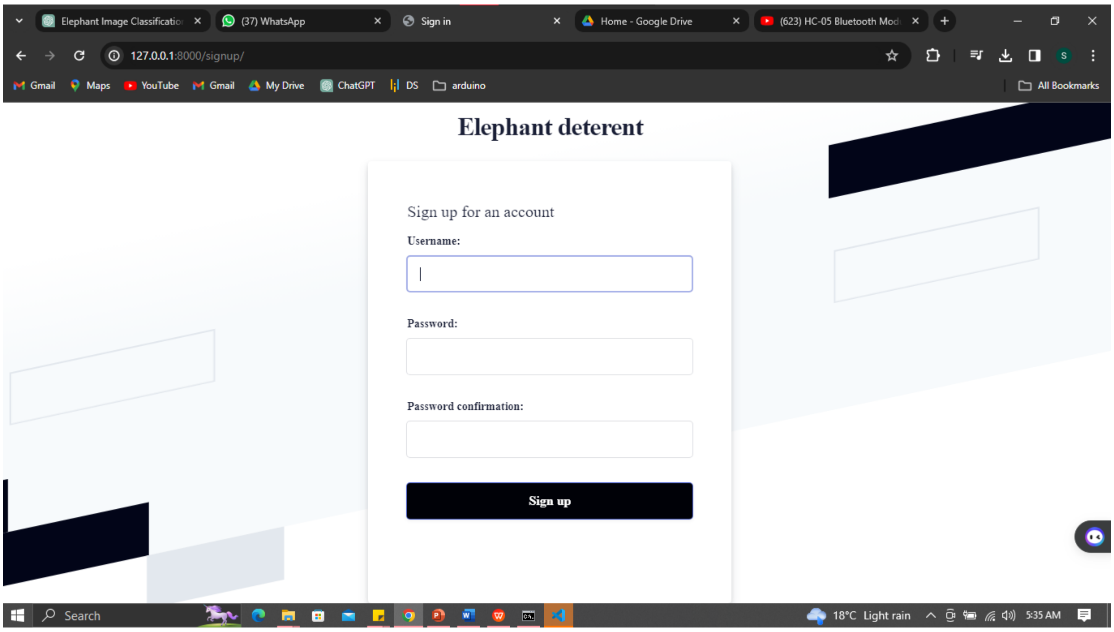

figure 5. 7 Proposed System Signup Page (author, 2024)

Then user selects an animal

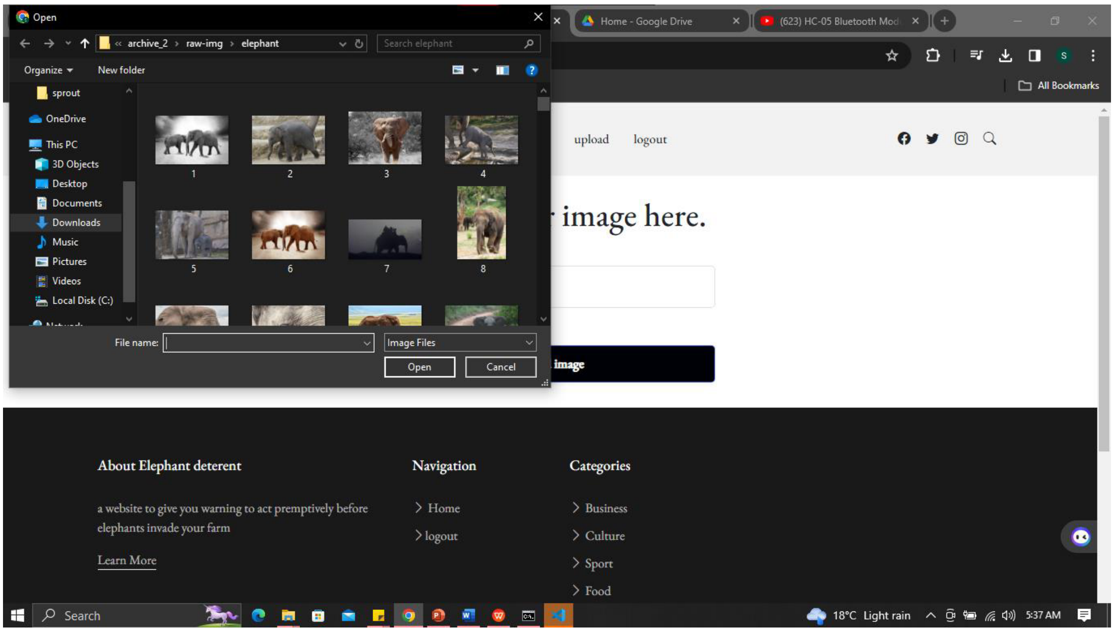

figure 5. 8 User Interacting with Form on Proposed System to Upload Image (Author, 2024)

User then receives success page

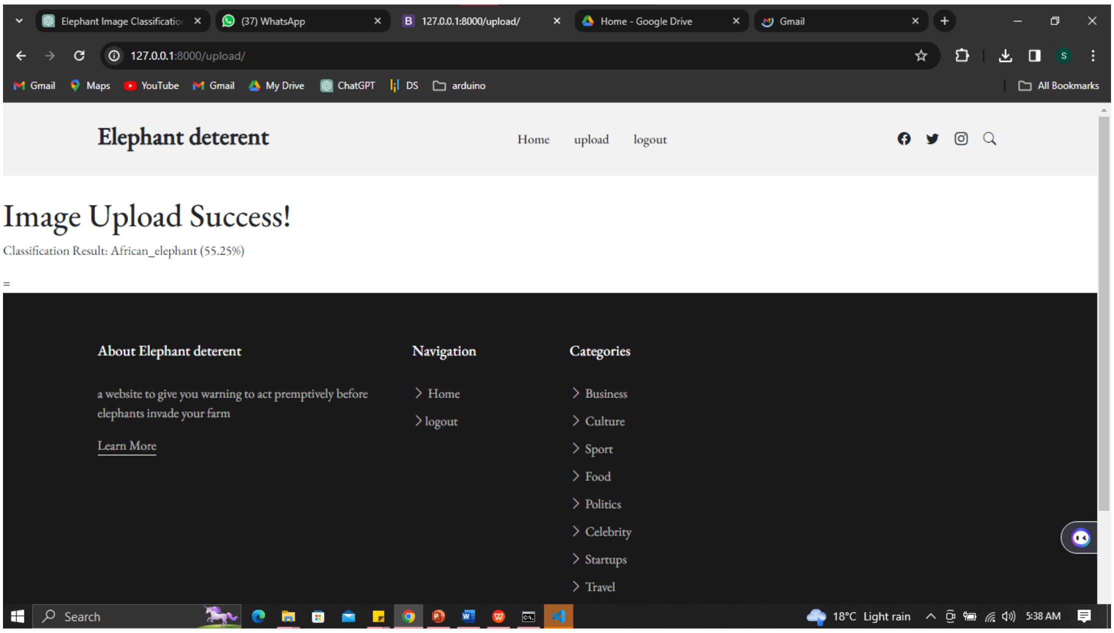

figure 5. 9 Success Page (Author, 2024)

An email alert is then sent to the farmer

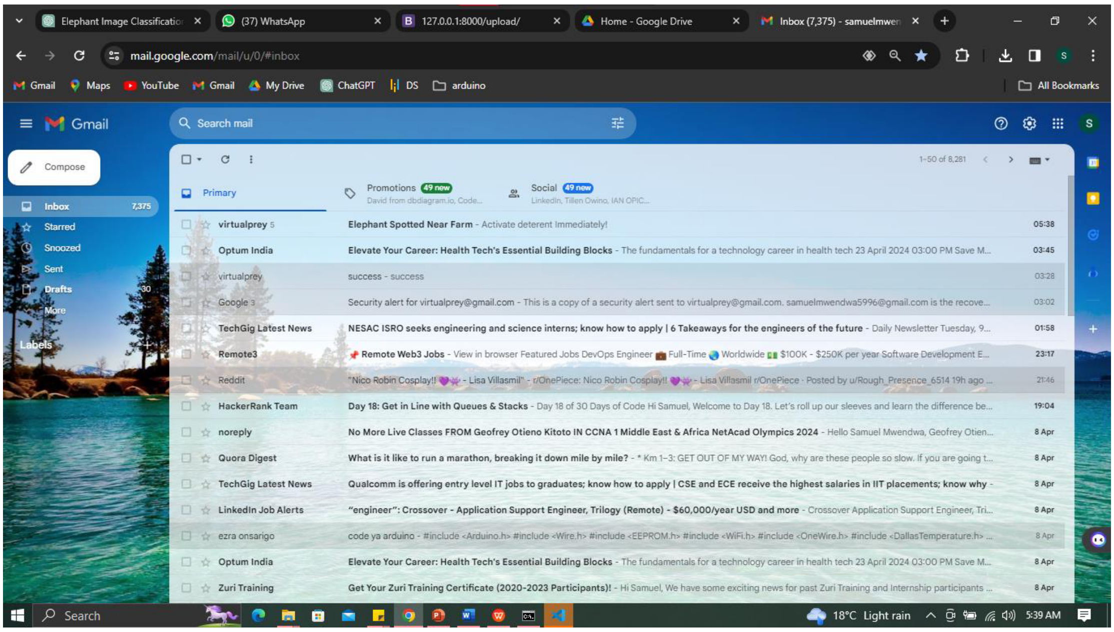

figure 5. 10 Email Page n Client (Author, 2024)

The farmer then starts the deterrent system from his phone

5.8 Chapter Summary

Chapter 5 of the research project delves into the system design of the proposed solution for preventing elephant intrusions in farms using IoT and AI technologies. The chapter begins with an introduction, providing an overview of the system design process. It then describes the proposed system, highlighting its strengths and weaknesses to provide insight into its capabilities and limitations. Following the description, the chapter conducts a comprehensive requirement analysis, covering functional, nonfunctional, user, and usability requirements. This analysis lays the groundwork for designing a system that meets the needs and expectations of stakeholders effectively.

The conceptual architecture of the proposed system is then presented, outlining the high-level design and interaction of key components such as IoT devices, AI algorithms, and web interfaces. This conceptualization provides a clear understanding of how the system operates and how its various elements work together to achieve the intended objectives. Subsequently, the chapter delves into the process logic design of the proposed system, presenting detailed diagrams including use case diagrams, activity diagrams, sequence diagrams, class diagrams, flow charts, context diagrams, and DFDS. These diagrams provide a visual representation of the system's behavior and logic, aiding in the understanding of its functionality.

Next, the chapter discusses the database design, covering entity-relationship (ER) modeling, normalization, and the creation of a data dictionary. This section focuses on designing a robust and efficient database structure to store and manage the system's data effectively. Finally, the chapter concludes with an overview of the input/output (I/O) of the proposed system, showcasing mock-up screens of the user interface. These mock-ups provide a glimpse into how users will interact with the system and visualize the user experience.

In summary, Chapter 5 comprehensively explores the system design aspects of the proposed solution, from conceptualization to detailed design and visualization of the user interface. It lays the foundation for the subsequent implementation and development phases of the project, ensuring a well-planned and structured approach to addressing the research problem.

CHAPTER SIX

Implementation System & Testing

6.1 Chapter Introduction

In this chapter, the focus shifts towards the practical implementation of the proposed system and the rigorous testing procedures employed to ensure its functionality and reliability. The chapter delves into the detailed process of translating the system design into a tangible product, highlighting key implementation steps, challenges encountered, and solutions devised. Additionally, it discusses the comprehensive testing plan devised to evaluate the system's performance, usability, and adherence to specified requirements. Through a combination of implementation insights and testing methodologies, this chapter provides a holistic view of the system's development journey, from conceptualization to real-world application.

6.2 System Screenshots

The landing page

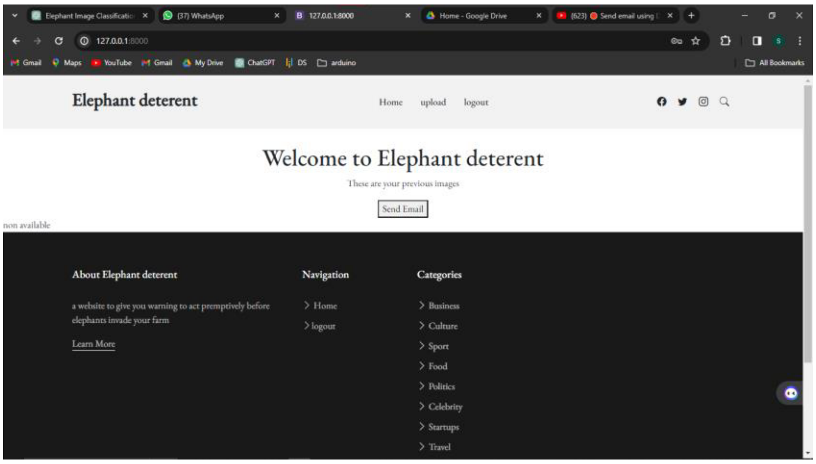

figure 6. 1 Landing Page (Author, 2024)

Upload image page.

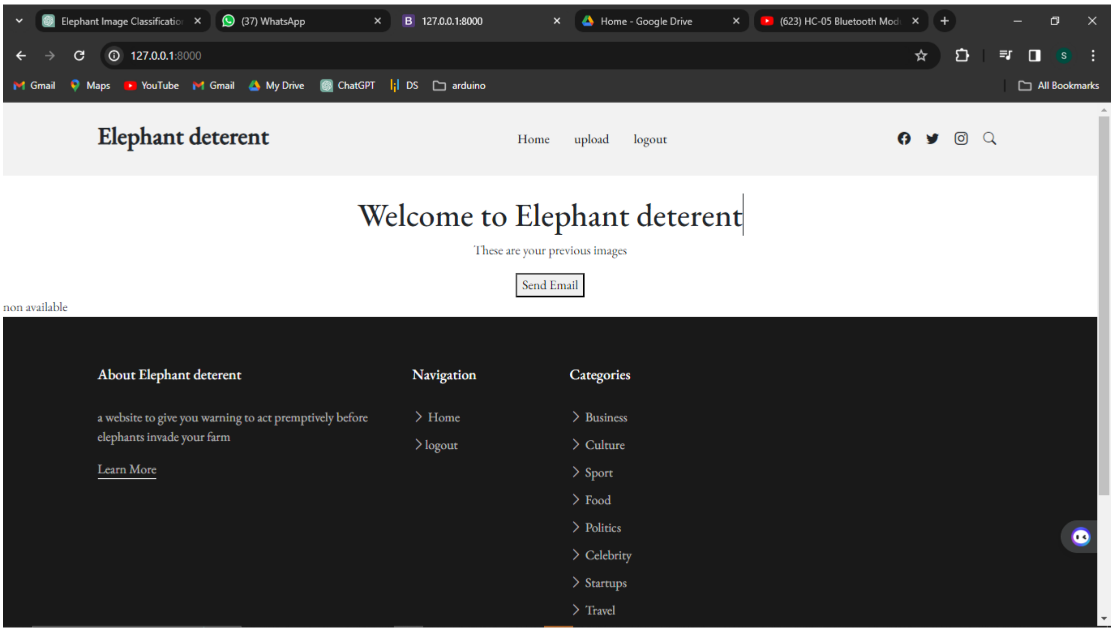

figure 6. 2 Upload Image (Author, 2024)

Remote activation page

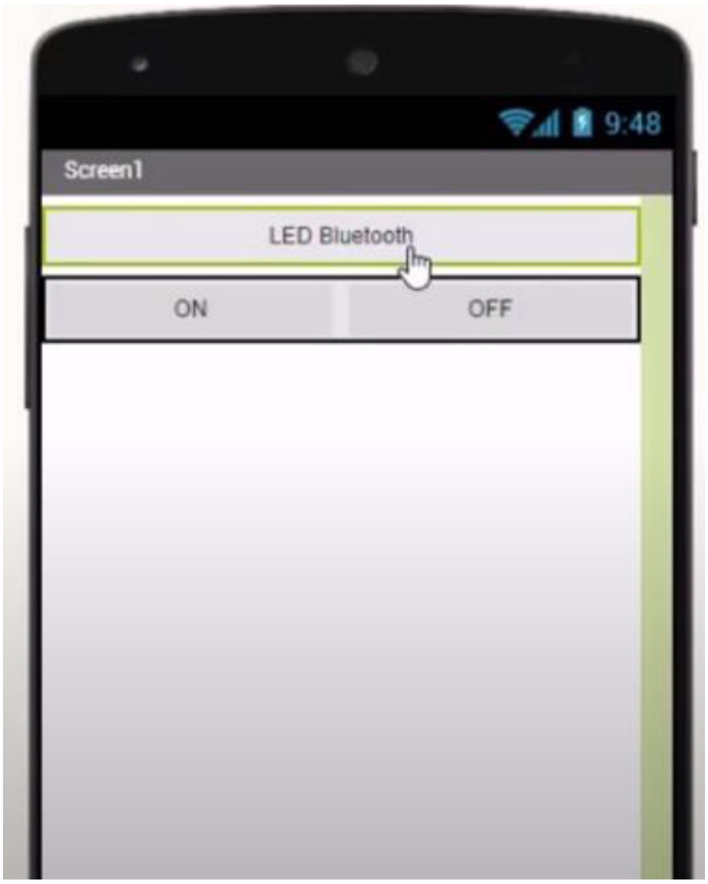

figure 6. 3 Mobile phone for remote activation of the deterrent (Author, 2024)

Arduino circuit

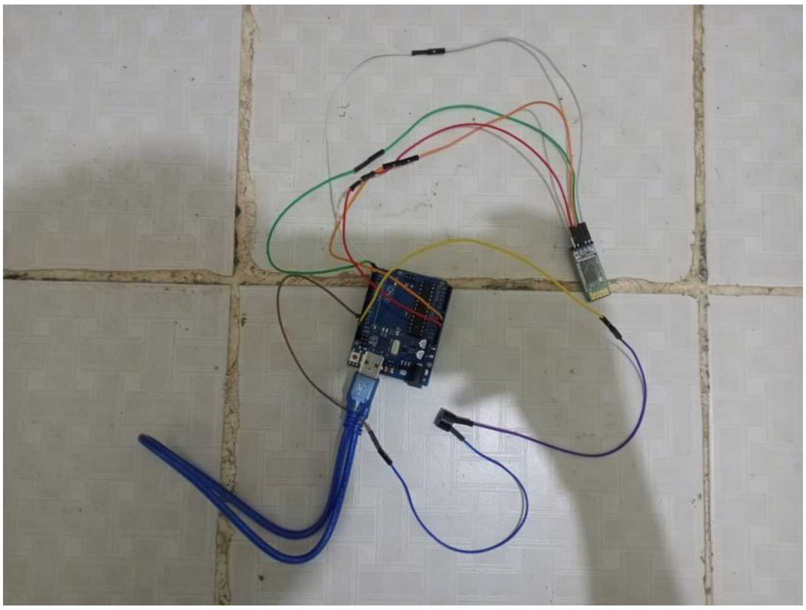

figure 6. 4 Arduino Uno circuit for the remotely activated deterrent (Author, 2024)

6.3 Testing Plan

6.3.1 Unit Testing

In the context of the current system, unit testing will involve the systematic examination of individual components and functionalities to ensure their accuracy and reliability (Raffin, 2021). Each module, including the image capture module, object detection algorithms, and communication protocols, will undergo thorough testing to verify its correctness and robustness. Test cases will be designed to validate the behavior of each unit under various input conditions and edge cases. For instance, the image capture module will be tested to ensure it captures images at regular intervals as intended, while the object detection algorithms will be validated for their ability to accurately identify elephants and other intruding animals. By conducting unit testing, the project team aims to detect and address any defects or inconsistencies at the component level, laying the groundwork for a stable and dependable system.

6.3.2 Integration Testing

Integration testing will focus on validating the seamless integration and interaction between different modules and components within the current system. This phase will involve combining the image capture module with the object detection algorithms, communication protocols, and user interface components to assess their interoperability and functionality as a unified system. Test scenarios will simulate data exchange between modules, ensuring that information flows smoothly and accurately throughout the system (Alli, 2020). For example, integration testing will verify that images captured by the camera are processed correctly by the object detection algorithms, and that alerts are generated and transmitted to the user interface as expected. By conducting integration testing, the project team aims to identify and resolve any integration issues or inconsistencies, ensuring the cohesive operation of the entire system.

6.3.3 System Testing

System testing will involve the comprehensive evaluation of the entire current system to validate its overall functionality, performance, and behavior (Zhang, 2020). This phase will assess the system's ability to detect elephants and other intruding animals in real-world scenarios, considering factors such as image quality, environmental conditions, and system responsiveness. Test scenarios will cover end-to-end workflows, from image capture and processing to alert generation and user notification. For instance, system testing will simulate different scenarios, such as daytime versus nighttime operation, to evaluate the system's performance under varying conditions. By conducting system testing, the project aims to ensure that the current system meets specified requirements and performs reliably in practical usage scenarios, thereby instilling confidence in its readiness for deployment.

6.3.4 Acceptance Testing

Acceptance testing will involve validating the current system's readiness for deployment from the end-user's perspective, ensuring that it meets stakeholder expectations and business objectives (Neil, 2008). This phase will engage end-users, such as farmers and agricultural experts, to assess the system's usability, effectiveness, and alignment with user needs. Test scenarios will replicate typical usage scenarios, allowing end-users to interact with the system and evaluate its performance firsthand. For example, acceptance testing will involve scenarios where farmers receive alerts about intruding animals and remotely activate deterrent measures using the user interface. By involving end-users in acceptance testing, the project team aims to gather valuable feedback, validate user acceptance, and address any outstanding issues or concerns before deploying the system in real-world agricultural settings.

6.4 Evaluation plan

The evaluation plan outlines the systematic approach for assessing the effectiveness, performance, and usability of the current system in real-world agricultural settings (Zhang, 2020). It encompasses various evaluation methods and criteria to measure the system's impact on crop protection, user satisfaction, and operational efficiency. The evaluation plan will be divided into several key components, each focusing on specific aspects of the system's functionality and performance.

6.4.1 Effectiveness Evaluation

The effectiveness evaluation will assess the system's ability to detect and repel intruding animals, particularly elephants, from agricultural fields (Raffin, 2021). This evaluation will involve comparing the system's detection accuracy and response time against predefined benchmarks and objectives (Raffin, 2021). Field tests will be conducted to simulate real-world scenarios and evaluate the system's performance under different environmental conditions and operational challenges. Effectiveness metrics, such as detection rates, false alarm rates, and deterrent success rates, will be measured and analyzed to determine the system's overall effectiveness in mitigating crop damage caused by intruding animals.

6.4.2 Performance Evaluation

The performance evaluation will focus on assessing the system's operational performance, including its responsiveness, reliability, and scalability (Zhang, 2020). Performance tests will be conducted to measure key performance indicators such as processing speed, system latency, and resource utilization under various load conditions. Stress testing will be performed to evaluate the system's robustness and stability under high traffic or resource-intensive scenarios. Performance benchmarks will be established based on industry standards and best practices to gauge the system's performance against predefined thresholds and requirements.

6.4.3 Usability Evaluation

The usability evaluation will examine the system's user interface, interaction design, and overall user experience to assess its ease of use, learnability, and user satisfaction. Usability tests will be conducted with end-users, including farmers and agricultural workers, to gather feedback on the system's usability and effectiveness in real-world usage scenarios (Zhang, 2020). Usability metrics, such as task completion time, error rates, and subjective user feedback, will be collected and analyzed to identify usability issues and areas for improvement. The usability evaluation aims to ensure that the system provides an intuitive and user-friendly interface that meets the needs and expectations of its target users.

6.4.4 User Acceptance Evaluation

The user acceptance evaluation will focus on assessing end-users' perceptions, attitudes, and willingness to adopt the current system in their daily agricultural practices (Neil, 2008). Surveys, interviews, and feedback sessions will be conducted with end-users to gather insights into their acceptance of the system, perceived benefits, and concerns. User acceptance metrics, such as satisfaction scores, adoption rates, and intention to continue using the system, will be measured and analyzed to assess user acceptance levels. The user acceptance evaluation aims to validate the system's alignment with user needs and expectations, ensuring its successful adoption and integration into agricultural workflows.

6.5 Chapter Summary

In this chapter, the implementation of the system and the comprehensive testing plan were discussed. The chapter began with an introduction highlighting the significance of implementing the system and ensuring its functionality through rigorous testing. The system screenshots provided a visual representation of the implemented solution, showcasing its key features and user interface elements. Following this, the testing plan was outlined, detailing the systematic approach to evaluating the system's performance and functionality. The testing plan covered various aspects, including functional testing, nonfunctional testing, user testing, and usability testing. Each testing component aimed to verify the system's adherence to requirements and assess its effectiveness in real-world scenarios.

Additionally, the evaluation plan was introduced, outlining the methods and criteria for assessing the system's effectiveness, performance, and usability. The evaluation plan encompassed effectiveness evaluation, performance evaluation, usability evaluation, and user acceptance evaluation. These evaluations aimed to provide insights into the system's impact on crop protection, operational efficiency, and user satisfaction. Overall, the implementation system and testing chapter provided a comprehensive overview of the steps taken to develop and validate the proposed solution. By combining implementation efforts with thorough testing and evaluation, the chapter laid the foundation for ensuring the system's functionality, reliability, and user acceptance in practical agricultural settings.

CHAPTER SEVEN

Conclusions, Findings & Recommendations

7.1 Introduction

This chapter presents the conclusions, findings, and recommendations derived from the research and implementation of the Intelligent Animal Repelling System for Crop Protection based on Embedded Edge-AI. It provides insights into the outcomes of the project and offers recommendations for future improvements and research directions.

7.2 Conclusion

After an extensive research endeavor and the implementation of the Intelligent Animal Repelling System for Crop Protection based on Embedded Edge-AI, several significant conclusions have been drawn. The system has proven to be a promising solution for mitigating the persistent challenge of ungulate attacks on agricultural crops. By leveraging edge-AI technology and real-time object detection algorithms, the system has demonstrated its efficacy in detecting and repelling animals effectively, thus safeguarding valuable crops from damage. One of the primary findings of this research is the system's capability to provide real-time monitoring and response to intruding animals, thereby minimizing crop losses and enhancing agricultural productivity. The integration of edge computing devices, such as Arduino and Wi-Fi modules, coupled with advanced image processing techniques, has enabled swift and accurate detection of ungulates, ensuring timely intervention to prevent crop damage.

Moreover, the implementation of remote activation of deterrent measures, such as the buzzer, and the generation of alerts to farmers have further enhanced the system's effectiveness. Farmers can now remotely manage and control the system through a web-based interface, receiving instant notifications upon animal detection and taking necessary actions to protect their crops, even from remote locations. The implications of these findings for the agricultural sector are profound. The Intelligent Animal Repelling System offers a practical and efficient solution to the age-old problem of wildlife intrusion in agriculture. By providing farmers with a proactive means of crop protection, the system not only mitigates economic losses but also contributes to sustainable farming practices and environmental conservation efforts.

However, it is essential to acknowledge the challenges encountered during the development and implementation of the system. Technical limitations, such as connectivity issues and algorithmic complexities, have posed hurdles that require careful consideration and continuous refinement. Addressing these challenges and further optimizing the system's performance will be crucial for its widespread adoption and long-term viability in agricultural settings. In conclusion, the Intelligent Animal Repelling System holds immense promise as a transformative technology in modern agriculture. Its ability to harness the power of edge-AI for real-time crop protection signifies a significant advancement in the field. Moving forward, continued research, innovation, and collaboration will be essential in realizing the full potential of this system and ensuring its positive impact on agricultural sustainability and food security.

7.3 Challenges Encountered.

Throughout the development and implementation phases of the Intelligent Animal Repelling System, several challenges were encountered, necessitating careful consideration and resolution strategies.

7.3.1 Technical Limitations

The technical limitations encountered during the development of the Intelligent Animal Repelling System primarily revolved around connectivity issues, particularly in remote agricultural areas with limited internet access. In such environments, ensuring reliable communication between edge devices and the central server posed significant challenges. Alternative networking solutions had to be explored, considering options like satellite communication or long-range wireless technologies to establish connectivity. Additionally, optimizing data transmission protocols became crucial to minimize latency and ensure efficient data exchange between the edge devices and the central server. These technical limitations highlighted the need for innovative approaches to overcome connectivity constraints and maintain system functionality in remote agricultural settings.

7.3.2 Algorithmic Complexities

The development and fine-tuning of object detection algorithms presented significant algorithmic complexities. Achieving accurate and efficient animal recognition required addressing various algorithmic intricacies, including optimizing model performance and minimizing false positives/negatives. Extensive experimentation and iterative refinement were essential to iteratively improve algorithm performance and enhance detection accuracy. Strategies such as dataset augmentation, hyperparameter tuning, and algorithm optimization played a vital role in overcoming algorithmic complexities and achieving satisfactory results. However, ongoing research and development efforts were necessary to further enhance algorithm robustness and effectiveness in real-world scenarios.

7.3.3 Hardware Compatibility

Integrating diverse hardware components, including Arduino, Wi-Fi modules, and cameras, posed compatibility challenges during system development. Ensuring seamless interoperability and synchronization between hardware devices and software modules required meticulous testing and validation. Compatibility issues were identified and addressed through comprehensive hardware testing procedures, including hardware compatibility testing and firmware updates. Additionally, establishing standardized communication protocols and interfaces facilitated smooth integration and interaction between different hardware components. Despite the challenges, overcoming hardware compatibility issues was essential to ensure the reliability and effectiveness of the Intelligent Animal Repelling System.

7.3.4 Environmental Variability

The system's performance was significantly influenced by environmental factors such as lighting conditions, weather changes, and terrain variations. Adapting the system to diverse environmental contexts and mitigating the impact of environmental variability on detection accuracy presented ongoing challenges. Adaptive algorithms and sensor calibration techniques were employed to address environmental variability and enhance system robustness. Continuous monitoring and adjustment of system parameters based on environmental conditions were essential to maintain optimal detection performance. Despite the challenges posed by environmental variability, addressing these factors was crucial to ensure the system's effectiveness and reliability in real-world agricultural environments.

7.3.5 Data Privacy and Security

Safeguarding sensitive data, including captured images and user information, emerged as a paramount concern for the Intelligent Animal Repelling System. Addressing data privacy and security challenges required the implementation of robust encryption methods, access controls, and authentication mechanisms. By encrypting data both in transit and at rest, the system aimed to prevent unauthorized access and data breaches. Access controls were enforced to restrict user permissions and ensure that only authorized individuals could access sensitive information. Additionally, implementing stringent authentication mechanisms, such as multi-factor authentication, bolstered the system's defenses against unauthorized access attempts. Compliance with regulatory requirements and user trust were central considerations in designing and implementing robust data privacy and security measures.

7.3.6 Operational Reliability

Maintaining operational reliability and system uptime posed significant challenges, particularly in dynamic agricultural environments characterized by power outages, equipment failures, and environmental hazards. To address these challenges, the system incorporated redundancy measures, remote monitoring capabilities, and rapid response protocols. Redundancy measures, such as backup power sources and redundant communication channels, were implemented to ensure continuous operation even in the event of failures. Remote monitoring capabilities enabled real-time monitoring of system status and performance, facilitating proactive intervention and troubleshooting. Rapid response protocols were established to enable swift action in response to critical events or system anomalies, minimizing downtime and disruptions to agricultural operations.

7.3.7 Cost Constraints

Balancing the system's performance requirements with cost constraints presented challenges in selecting and procuring hardware components and software resources. The optimization of resource utilization and exploration of cost-effective alternatives were key strategies employed to mitigate cost constraints. By prioritizing essential functionalities and avoiding unnecessary overhead, the system aimed to achieve cost-effectiveness without compromising effectiveness or scalability. Furthermore, leveraging open-source technologies and adopting modular design principles enabled cost-efficient development and deployment of the system. Despite the inherent challenges posed by cost constraints, strategic decision-making and prudent resource allocation were instrumental in ensuring the system's affordability and sustainability in the long term.

7.4 Future Recommendations

As the Intelligent Animal Repelling System progresses towards deployment and real-world implementation, several future recommendations can enhance its effectiveness, reliability, and scalability. These recommendations include:

7.4.1 Enhanced Connectivity Solutions

In the context of the proposed animal repelling system for agricultural protection, the exploration of alternative connectivity solutions is paramount to address the challenges posed by remote agricultural areas with limited internet access. Satellite or mesh networks present promising options for ensuring reliable data transmission and system operation even in remote locations where traditional internet infrastructure is lacking. By leveraging these technologies, the system can maintain connectivity with edge devices deployed across agricultural fields, facilitating real-time data exchange and coordination. Hybrid communication systems, combining satellite, mesh, and other communication technologies, offer a versatile approach to overcome connectivity limitations, providing redundancy and resilience to network disruptions. The implementation of enhanced connectivity solutions will not only bolster the system's reliability but also extend its reach to areas previously inaccessible, thereby enhancing its effectiveness in protecting crops from wildlife threats.

7.4.2 Advanced Algorithm Development

Continuous refinement and optimization of object detection algorithms are essential for enhancing the performance and effectiveness of the animal repelling system. In the agricultural context, where accurate and efficient detection of wildlife intrusions is critical, ongoing research and development efforts should focus on advancing AI techniques tailored to animal recognition and behavior prediction. Deep learning and reinforcement learning offer promising avenues for improving the accuracy and adaptability of detection algorithms, enabling the system to differentiate between target animals and non-threatening entities accurately. By investing in advanced algorithm development, the system can evolve to address emerging challenges and scenarios, ensuring proactive and reliable detection of wildlife threats to agricultural crops.

7.4.3 Integrated Environmental Sensors

The integration of environmental sensors into the animal repelling system augments its capabilities by providing real-time insights into environmental conditions that may influence wildlife behavior and crop vulnerability. Weather stations, soil moisture sensors, and other environmental monitoring devices offer valuable data on factors such as temperature, humidity, and soil conditions, enabling the system to adapt its deterrent strategies accordingly. By incorporating data from these sensors into decision-making processes, the system gains a holistic understanding of the agricultural environment, allowing for proactive measures to mitigate risks and optimize crop protection efforts. Integrated environmental sensors not only enhance the system's resilience to environmental variability but also contribute to sustainable agricultural practices by optimizing resource utilization and minimizing environmental impact.

7.4.4 Comprehensive Data Privacy Measures

As the animal repelling system collects and processes sensitive data, including captured images and user information, safeguarding data privacy is paramount to maintain user trust and comply with regulatory requirements. Implementing comprehensive data privacy measures, such as anonymization techniques and privacy-preserving protocols, is essential to protect user privacy and prevent unauthorized access or misuse of data. Regular audits and assessments of data handling practices ensure ongoing adherence to privacy best practices and standards, fostering transparency and accountability in data management. By prioritizing data privacy and security, the system not only mitigates the risk of data breaches but also builds a foundation of trust with users and stakeholders, supporting the sustainable deployment and adoption of the technology in agricultural settings.

7.4.5 Scalability and Modularity

Designing the animal repelling system with scalability and modularity as core principles ensures its readiness to accommodate future growth and customization needs. By standardizing interfaces and protocols, the system can seamlessly integrate with a variety of third-party devices and systems, enhancing interoperability and scalability within agricultural ecosystems. Modular architecture allows for flexible expansion and modification, enabling the addition of new features or the integration of advanced technologies as agricultural requirements evolve. Scalability and modularity not only future-proof the system but also foster innovation and adaptability, empowering farmers and agronomists to tailor the system to their specific needs and preferences effectively.

7.4.6 Community Engagement and Collaboration

Community engagement and collaboration play a pivotal role in the successful deployment and adoption of the animal repelling system in agricultural contexts. Establishing partnerships with agricultural communities, research institutions, and governmental agencies fosters knowledge exchange, resource sharing, and collective problem-solving. Collaborative efforts on research projects and pilot programs leverage local expertise and insights, ensuring that the system's design and functionality align with the needs and realities of end-users. By actively involving stakeholders throughout the development process, the system can garner support, build trust, and cultivate a sense of ownership within the agricultural community, ultimately enhancing its effectiveness and sustainability.

7.4.7 Continuous Monitoring and Evaluation

Continuous monitoring and evaluation are essential components of an adaptive and effective animal repelling system, allowing for ongoing assessment of its performance, reliability, and impact in real-world agricultural settings. Establishing robust mechanisms for gathering feedback from end-users, stakeholders, and domain experts provides valuable insights into the system's strengths, weaknesses, and areas for improvement. Regular evaluation activities, such as field trials, user surveys, and performance assessments, enable iterative refinement and optimization of the system over time. By embracing a culture of continuous improvement, the system can evolve in response to changing agricultural dynamics and emerging challenges, ensuring its long-term viability and relevance in crop protection efforts.

7.5 Conclusion

In conclusion, the development of the Intelligent Animal Repelling System represents a significant step forward in leveraging edge computing and AI technologies to address the pressing challenge of crop protection against ungulate attacks in agriculture. Throughout the project, a prototype system was conceptualized, designed, and evaluated, aiming to provide farmers and agronomists with an effective tool to mitigate crop damage and enhance agricultural sustainability. The proposed system demonstrated several strengths, including real-time animal detection, remote activation of deterrent measures, and seamless integration with a web-based user interface for remote control and monitoring. These features, coupled with robust security measures and usability enhancements, underscored the system's potential to revolutionize crop protection practices and foster resilience in agricultural operations.

However, the project also encountered challenges, such as technical limitations, algorithmic complexities, and operational constraints, which underscored the need for continuous innovation and improvement. Addressing these challenges will require further research and development efforts, including the exploration of enhanced connectivity solutions, advanced algorithm development, and comprehensive data privacy measures. Looking ahead, future recommendations emphasize scalability, community engagement, and continuous monitoring and evaluation as critical pillars for the success of the Intelligent Animal Repelling System. By embracing these recommendations and fostering collaboration across stakeholders, the system can evolve into a robust and adaptive solution that empowers agricultural communities to safeguard their crops effectively while promoting environmental sustainability and economic prosperity. Through dedication to innovation and collaboration, the Intelligent Animal Repelling System holds the promise of transforming crop protection practices and ushering in a new era of resilience in agriculture.

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Appendix

Appendix I Questionnaire

Intelligent Animal Repelling System Questionnaire

Dear Participant,

Thank you for participating in this survey. Your input is invaluable for the development of an Intelligent Animal Repelling System aimed at mitigating human-elephant conflict in Taita-Taveta County, Kenya. Please take a moment to provide your thoughtful responses.

a)	Strongly agree	agree	neutral	Disagree	Strongly disagree
Are you confident in the ability of image processing technology to accurately identify elephants on your farm?	○	○	○	○	○
Do you believe that accurate identification of elephants through image processing technology can enhance the safety and security of your farm?	○	○	○	○	○
Do you encounter challenges or errors in the identification process when using image processing technology to detect elephants?	○	○	○	○	○
Are you satisfied with the accuracy of the current image	○	○	○	○	○

processing technology in identifying elephants compared to other methods (e.g., manual observation)?					
Should we continually invest in improving the accuracy and efficiency of elephant identification through advancements in image processing technology?					
b)					
Do you consider receiving immediate alerts about elephant presence on your farm for timely intervention important?					
Are you satisfied with the timeliness of the current alert system when detecting elephants on your farm?					
Does the reliability of the alert system impact your overall perception of farm security against elephant intrusions?					
Is it for you to have multiple communication channels for receiving alerts about elephant detection (e.g., SMS, email, mobile app)?					
c)					
Do you find yourself needing to activate deterrence systems					

remotely upon detecting elephants on your farm?					
Is remote activation and deactivation of a deterrent system better than traditional manual on-site activation?					
Do you prefer web activation or app activation?					

Table Appendix 1.1 A Questionnaire in table form (Author, 2024)

Appendix II: Sample Code

```
#include <WiFi.h>
#include <WiFiClient.h>
#include <WebServer.h>
#include <ESPmDNS.h>

const char* ssid = "XRT";
const char* password = "1m@n1D10t";

WebServer server(80);

const int led = 2;  // Built-in LED is usually on GPIO 2
const int buzzer = 13;  // D7 corresponds to GPIO 13
bool ledState = false;
bool buzzerState = false;
```

```
void handleRoot() {
  Serial.println("Handling root endpoint");
  String html = "<!DOCTYPE html><html><head><title>Elephant Deterrent</title>";
  html += "<style>";
  html += "body { background-color: #111; color: #fff; font-family: 'Chivo', sans-serif; text-align: center; margin: 0; padding: 0; height: 100vh; display: flex; justify-content: center; align-items: center; }";
  html += ".container { display: flex; flex-direction: column; align-items: center; }";
  html += ".title { color: #800080; font-size: 36px; margin-bottom: 20px; }";
  html += ".button {height:100; width:100; background-color: #800080; border: none; color: white; padding: 40px 40px; text-align: center; text-decoration: none; font-size: 24px; margin: 4px 2px; cursor: pointer; border-radius: 1rem; outline: none; box-shadow: 0 5px 15px rgba(0, 0, 0, 0.3); transition: background-color 0.3s ease; }";
  html += ".button:hover { background-color: #6a006a; }";
  html += "</style></head><body>";
  html += "<div class=\"container\">";
  html += "<h1 class=\"title\">Elephant Deterrent</h1>";
  html += "<button class=\"button\" id=\"deterrentButton\">Activate Deterrent</button>";
  html += "</div>";
  html += "<script>";
  html += "var deterrentState = false;";
  html += "var button = document.getElementById('deterrentButton');";
  html += "button.addEventListener('click', function() {";
  html += "  deterrentState = !deterrentState;";
  html += "  if (deterrentState) {";
  html += "    button.textContent = \"Deactivate Deterrent\";";
  html += "    fetch('/toggleBuzzer')";
  html += "      .then(response => response.text())";
  html += "      .then(data => console.log(data))";
  html += "      .catch(error => console.error('Error:', error));";
  html += "  } else {";
  html += "    button.textContent = \"Activate Deterrent\";";
  html += "    fetch('/toggleBuzzer')";
```

```
  html += "      .then(response => response.text())";
  html += "      .then(data => console.log(data))";
  html += "      .catch(error => console.error('Error:', error));";
  html += "  }";
  html += "});";
  html += "</script>";
  html += "</body></html>";
  server.send(200, "text/html", html);
}



void handleToggleLed() {
  Serial.println("Toggling LED state");
  ledState = !ledState;
  digitalWrite(led, ledState ? HIGH : LOW);
  server.send(200, "text/plain", ledState ? "LED is ON" : "LED is OFF");
}

void handleToggleBuzzer() {
  Serial.println("Toggling Buzzer state");
  buzzerState = !buzzerState;
  if (buzzerState) {
    ledcAttachPin(buzzer, 0);       // Attach pin to channel 0
    ledcSetup(0, 10000, 8);          // Setup channel 0 with 25 kHz frequency and 8-bit
resolution
    ledcWrite(0, 128);              // 50% duty cycle to make the buzzer sound
  } else {
    ledcWrite(0, 0);                // Turn off buzzer
    ledcDetachPin(buzzer);          // Detach pin from channel 0
  }
  server.send(200, "text/plain", buzzerState ? "Buzzer is ON" : "Buzzer is OFF");
}
```

```
void handleNotFound() {
  digitalWrite(led, HIGH);
  Serial.println("Handling not found endpoint");
  String message = "File Not Found\n\n";
  message += "URI: ";
  message += server.uri();
  message += "\nMethod: ";
  message += (server.method() == HTTP_GET) ? "GET" : "POST";
  message += "\nArguments: ";
  message += server.args();
  message += "\n";
  for (uint8_t i = 0; i < server.args(); i++) {
    message += " " + server.argName(i) + ": " + server.arg(i) + "\n";
  }
  server.send(404, "text/plain", message);
  digitalWrite(led, LOW);
}

void setup(void) {
  pinMode(led, OUTPUT);
  pinMode(buzzer, OUTPUT);
  digitalWrite(led, LOW);
  digitalWrite(buzzer, LOW);
  Serial.begin(115200);
  Serial.println("Serial communication started");

  WiFi.mode(WIFI_STA);
  WiFi.begin(ssid, password);
  Serial.print("Connecting to WiFi");

  // Wait for connection
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
```

```
  }
  Serial.println();
  Serial.print("Connected to ");
  Serial.println(ssid);
  Serial.print("IP address: ");
  Serial.println(WiFi.localIP());

  if (MDNS.begin("esp32")) {
    Serial.println("MDNS responder started");
  }

  server.on("/", handleRoot);
  server.on("/toggleLed", handleToggleLed);
  server.on("/toggleBuzzer", handleToggleBuzzer);
  server.on("/inline", []() {
    server.send(200, "text/plain", "this works as well");
  });

  server.onNotFound(handleNotFound);

  server.begin();
  Serial.println("HTTP server started");
}

void loop(void) {
  server.handleClient();
  delay(2); // Allow the CPU to switch to other tasks
}
```