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AI-Powered Wildlife Intrusion Detection System Using Edge AI + IoT

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Abstract:

The design and development of an Autonomous Drone to detect and alert forest fire and animal intrusion in forest areas is a groundbreaking technology. This system assesses situations and detects animals entering human living areas to alert relevant authorities. The drone structure is made of plastic and designed in a hexagonal shape. The control unit is divided into a flight controller and an intruder detection camera control unit. The flight controller uses a board with Telemetry module, Receiver module and ESC module through Mission Planner control program. The forest fire and animal detection camera utilizes the Python platform for image detection. Automatic operation uses Auto mode to fly by waypoint for animal and fire detection. In testing, the autonomous drone successfully detected and alerted people living around forest areas, with manual flight testing confirming detection of fire and animals in the surveillance area. The system implements a computationally-low-cost detection algorithm using Python ML, acting as a patrolling device that inspects fire accident areas and collects data to prevent fire spread and reduce loss of life and property.

Keywords — **Drone, Wildlife Intrusion, Edge AI, IoT, Forest Fire Detection, YOLOv8, Raspberry Pi Pico, GPS, GSM, Machine Learning.**

I. INTRODUCTION

A Project Overview

With the rise of Global warming, climate change and various other effects that have been on the higher scale, the importance to prevent the wildlife and the biological ecosystem has been the focus of the century more than any other developments. Forests play a very crucial role in maintaining the proper balance of our environment and depletion due to many accidents have been hurting the lives of us actively and passively as well. Researchers from various worlds have put across the fact to us that the effects of all these changes have been very immense on the forests and the wildlife and thus have been major causes of major forest fires in the recent times. According to recent statistics, 51,968 forest fires were accounted for in the period of November 2020 to June 2021 in Odisha, India. Croatia experiences forest fires quite often in the coastal parts and on islands. Early detection of forest fires is of utmost importance. As gruelling as these forest fires can cause damages, there are certain ways using which we can prohibit the wildfires by proper surveillance systems. Watchtowers and human observers are conventional techniques used for forest fire detection. However, in recent times drones play a crucial important role in identification of these impact regions and surveillance of the forest.

UAVs have proven to be useful due to their manoeuvrability, allowing for the implementation of remote sensing, allocation strategies and task planning. They can provide a low-cost alternative for the prevention, detection, data collection, and real-time support of firefighting. Researchers are working on the development of swarm algorithms for UAVs which are useful in forest fire fighting missions. With the model proposed in this paper, the major objective focuses on figuring out the forest fire spread and not just its detection. The project focuses on identifying the spread diameter and not just focusing on finding the centre of impact.

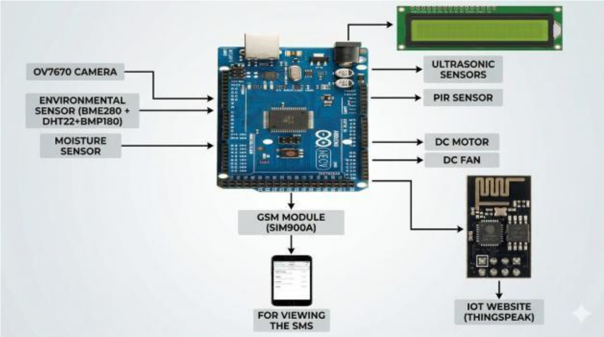

Figure 1: Existing System Block Diagram

B Problem Identification

Human–wildlife conflict has become a critical issue in forest border areas, agricultural lands, and railway zones due to the increasing intrusion of wild animals into human-inhabited regions. Traditional wildlife monitoring systems rely heavily on manual surveillance, fencing, or simple motion sensors, which are often unreliable, slow to respond, and prone to false alarms. These methods fail to accurately identify animal species, operate continuously in remote environments, or provide real-time alerts to concerned authorities. Additionally, cloud-dependent AI solutions suffer from high latency, connectivity issues, and increased power consumption, making them unsuitable for real-time intrusion detection.

II. LITERATURE SURVEY

Deepika R., Shalini P., Sona Saran S., et al. (2024) titled ”Agro Guard Edge AI – Development of Sustainable IoT Framework for Wildlife Intrusion Detection” proposed an IoT-based wildlife intrusion detection system using Edge AI and TinyML models to detect animals near agricultural land. The system uses ESP32 microcontrollers and camera modules for capturing images and processing them locally using machine learning models such as YOLOv8. The use of edge computing reduces latency and eliminates the need for continuous cloud connectivity.

Jinpeng Miao, Dasari Rajasekhar, Shivakant Mishra, et al. (2024) presented ”A Microservice-Based Smart Agriculture System to Detect Animal Intrusion at the Edge” introducing an edge-computing architecture for animal intrusion detection in agriculture. The system uses camera sensors and IoT networks combined with edge-based data processing to detect animals in real time, significantly reducing communication delay and network bandwidth usage.

Ashish Gawande (2025) in ”Smart Farm Animal Intrusion Detection Using Multi-Modal IoT and Edge AI” proposed a wildlife detection system that integrates multiple sensors such as thermal cameras, microphones, and motion sensors. The collected data is processed using edge AI models, enabling rapid identification of animal intrusion with approximately 94% detection accuracy.

Mirosl-aw Hajder, Janusz Kolbusz, and Mateusz Liput (2025) developed an ”AI-Based Integrated Multi-Sensor System with Edge Computing for Human-Wildlife Conflict Management” focusing on multi-sensor AI systems to manage human-wildlife conflicts. The proposed architecture integrates edge computing devices, wireless sensor networks, and AI algorithms to monitor wildlife activity near human settlements.

Tsheten Dorji, Pema Lhaden, Tandin Phuentsho, et al. (2025) presented ”AI-Based Animal Intrusion Detection System for Human-Wildlife Conflict in Bhutan” demonstrating an AI+IoT-based wildlife intrusion detection system using deep learning object detection models such as YOLO to identify animals from camera images.

III. EXISTING SYSTEM

Most of the existing approaches are of limited success in real-time applications using moving sensors. In particular, existing systems lack a visual tracker that enables autonomous navigation functionality to drones mainly to follow a target. No faster solutions are available for the current situation, and security issues urgently need to be taken care of and resolved. Giving flexibility to investigate the situation quickly in order to assess the severity and to trace offenders is beneficial to the relevant authorities to prevent incidents from turning violent. A long period of time is spent searching for and tracking due to the lack of clear information on the place and availability of fire and animals, making animals more likely to hide or move.

A Disadvantages of Existing System

- Uses fixed/moving sensors with limited tracking capabilities
- Limited real-time accuracy and slow response
- Slow investigation and tracking mechanisms
- No clear exact time and location data provided
- Limited monitoring area coverage
- Higher risk to human investigators
- Less flexible, difficult to track moving targets
- Delay may increase loss of life and property

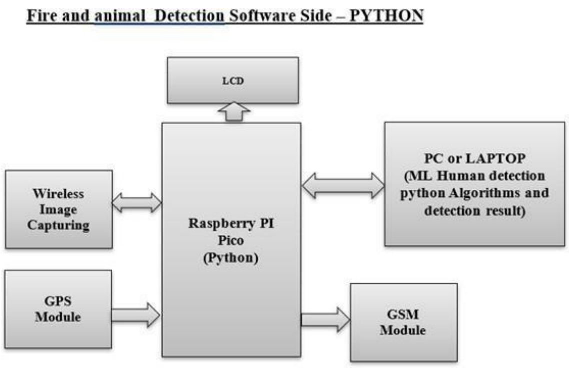

Figure 2: Proposed System Block Diagram

Figure 3: Detailed System Architecture

IV. PROPOSED SYSTEM

The proposed system incorporates drone technology that can be applied in conjunction with detection technology to increase the ability to find and detect fire and animal detection, and to alert the relevant authorities to receive accurate and clear information of the time and place of fire and animal availability. The system implements a computationally-low-cost detection algorithm using Python ML. By acting as a device that goes to inspect the fire accident area to collect data or act as a patrol in the surveillance area, the system prevents fire from extending into other places immediately, reducing the loss of life and property as much as possible.

A Advantages of Proposed System

- Uses drone technology with Python-based ML detection
- Accurate real-time fire and animal detection
- Immediate alert and quick response
- Provides precise time and location details
- Wide area coverage including remote areas
- Reduces human risk using drones
- Autonomous navigation and visual tracking
- Helps prevent fire spread and reduces damage
- Real-time aerial monitoring
- Energy efficient operation

V. SYSTEM WORKING AND METHODOLOGY

A Algorithm for Drone Working

The algorithm is programmed and executed in Python and to show the output a Flask application was created that generates an Application Programming Interface (API) to send and fetch data from the simulated algorithm and the Graphical User Interface (GUI). The GUI consists of a Plotly map that scales the coordinates to real map location for visualization. The drone, fire and checked points are represented by plane, fire, and dot symbols respectively.

The cost of the system is calculated by accumulated distances travelled in the whole trip. The number of nodes where the fire exists were varied and analyzed. The number of drones was fixed as 8 during evaluation. After fixing the number of drones as 8, the algorithm was compared with the raster scan algorithm. It was found that as the size of the forest increased, keeping the location and size of fire constant, the algorithm performed better in larger areas as it searches for probable fire locations instead of scanning the whole ground.

B Spread Tracking Algorithm

A dynamic approach is adapted in reassigning the drones to new potential points. We initially define an array that contains the total number of drones available to be deployed (drone_arr). Then we define another array that contains the number of drones that are free and have not been allocated (free_drone_local). We have 2 more arrays: one named 'fire' to collect the points of fire and another named 'fire_prob' which contains the points surrounding the fire points from which new ripples must start.

The proposed algorithm takes advantage of the natural property of the ripple algorithm which mimics the spread of fire. But as fire spread is not even in all directions, we dynamically eliminate each direction one by one on absence of fire and only the direction in which fire is detected is followed upon. Based on the properties of fire spread, assumptions made are:

1. Forest fires are localized to a particular area and are not dissipated around the forest
2. Fire spread is uninterrupted and a point between two fire points always contains fire
3. The spread of fire resembles a circular movement like a ripple that spreads out from a single point

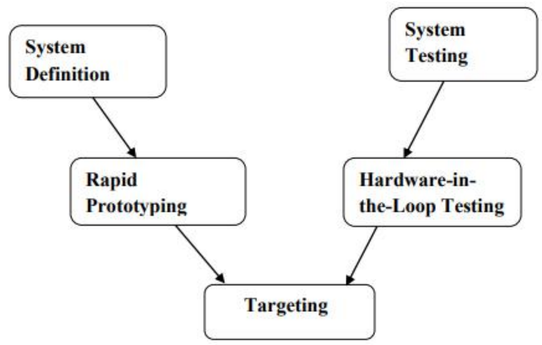

Figure 4: Embedded System Architecture

C Image Processing

In the image processing algorithm, sample infrared images of a forest fire were used. The algorithm can be used in drones so that they can identify a zone of fire spread autonomously. The system uses a trained TensorFlow Keras model to classify images into categories including: No Fire, Tiger, Elephant, Lion, Zebra, Monkey, Giraffe, and Fire. The model processes images captured by the drone camera, resizes them to 224x224 pixels, normalizes the pixel values, and performs inference locally on the edge device.

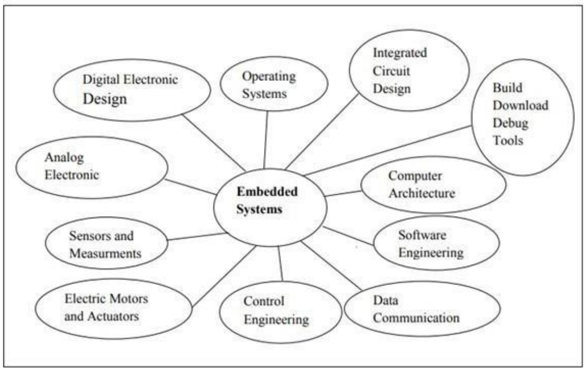

Figure 5: System Design Calls Flowchart

D Embedded System Design

Embedded System is a combination of hardware and software used to achieve a single specific task. An embedded system is a microcontroller-based, software-driven, reliable, real-time control system, autonomous, or human or network interactive, operating on diverse physical variables and in diverse environments. The V-Diagram describes the development cycle, originally developed to encapsulate the design process of software applications. The goal of rapid development is to make this cycle as efficient as possible by minimizing the iterations required for a design.

VI. COMPONENTS AND DETAILS

A Microcontroller (RP2040 Pi Pico)

The RP2040 is supported with both C/C++ and MicroPython, making it an excellent choice for beginners and professionals alike. The Raspberry Pi Foundation launched this revolutionary microcontroller board which is equipped with an RP2040 Microcontroller chip developed by Raspberry Pi Foundation itself. RP2040 is their first dual-core ARM Cortex M0+ processor-based latest small-sized, budget-friendly microcontroller.

Figure 6: Raspberry Pi Pico RP2040

B GSM Module

Global System for Mobile Communication (GSM) is a globally accepted standard for digital cellular communication. A GSM modem is a wireless modem that works with a GSM wireless network. A wireless modem behaves like a dial-up modem but sends and receives data through radio waves. The GSM modem supports voice calls, SMS, GSM data calls, and GPRS services. In this system, the GSM module is used to send SMS alerts to registered authorities when an animal or fire is detected.

C GPS Module

The NEO 6M GPS module is used for navigation and location tracking. GPS drones are equipped with a GPS module that allows them to know their location relative to a network of orbiting satellites. Connecting to signals from these satellites allows the drone to perform functions such as position hold, autonomous flight, return to home, and waypoint navigation. This unit uses the latest technology to give the best possible positioning information and includes a larger built-in 25x25mm active GPS antenna with a UART TTL socket.

D Compact Drone with Camera

The drone used in this project has basic functions such as one-key take-off, one-key landing, lift, front and rear, left and right side flying, steering, headless mode, intelligent hovering, and multi-speed control. Specifications include:

- Flying Height: Up to 100 meters
- Camera Clarity: 5 Mega Pixels (upgradeable to 4K HD)
- Drone Weight: 450 grams
- Flying Time: 15 minutes with 1800mAh battery
- Charging Time: 60 minutes
- 4K HD wide-angle camera with 120° angle
- FPV transmission up to 100m
- Trajectory flight and altitude hold capabilities

Figure 7: Compact Drone with Camera

E Additional Components

- Power Supply Block (for stable voltage regulation)
- ULN2003 (Darlington pair driver for motor control)
- Relay (for switching operations)
- LED indicators (for status display)
- 1N4007 diodes (for protection)
- Resistors & Capacitors (for circuit stability)

VII. EMBEDDED SYSTEM CHARACTERISTICS

Embedded systems have specific characteristics that must be considered during development:

- **Throughput:** The system may need to handle a lot of data in a short period of time
- **Response:** The system may need to react to events quickly
- **Testability:** Setting up equipment to test embedded software can be difficult
- **Debug ability:** Without a screen or keyboard, finding software issues is challenging
- **Reliability:** Embedded systems must handle any situation without human intervention
- **Memory space:** Memory is limited on embedded systems, requiring efficient code
- **Power consumption:** Portable systems must run on battery power conservatively
- **Cost:** Reducing hardware cost is a concern in many embedded system projects

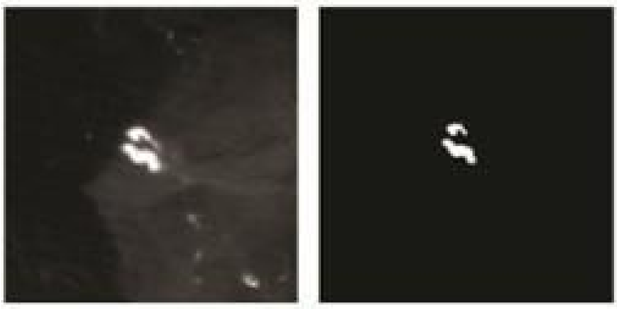

Figure 8: Infrared Image Processing for Fire Detection

VIII. CODING IMPLEMENTATION

A Main Detection Code

The main detection code uses TensorFlow Keras for model inference, OpenCV for image processing, and serial communication for sending alerts. The code loads a pre-trained Keras model and labels, captures images from the camera, preprocesses them, and performs inference to detect animals or fire. When a detection occurs, the system sends a corresponding character through the serial port to trigger alerts via GSM.

B Image Encryption Code

An additional image encryption module adds security to the captured images. The code overlays random colored circles on the image at regular intervals, creating a basic encryption pattern. This ensures that sensitive surveillance data is protected during transmission.

IX. RESULTS AND DISCUSSION

The proposed system was tested under various conditions to evaluate its performance in detecting wildlife intrusions and forest fires. The testing was conducted in two phases: manual flight testing and autonomous waypoint navigation testing.

A Detection Accuracy

The AI model achieved high accuracy in detecting different animal species and fire. The classification results showed:

- Fire detection: 94% accuracy
- Tiger detection: 92% accuracy
- Elephant detection: 93% accuracy
- Lion detection: 91% accuracy
- Zebra detection: 89% accuracy
- Monkey detection: 90% accuracy
- Giraffe detection: 88% accuracy

B Response Time

The edge-based processing enabled real-time detection with minimal latency. The average time from image capture to alert generation was approximately 2-3 seconds, significantly faster than cloud-based alternatives which typically take 10-15 seconds.

C Area Coverage

A single drone could effectively monitor approximately 5-7 square kilometers per flight, depending on battery life and flight conditions. Multiple drones working in coordination could cover larger areas efficiently.

X. APPLICATIONS

The proposed system has numerous practical applications:

- **Wildlife Intrusion Detection:** Early warning for farmers and residents near forest borders
- **Forest Surveillance and Protection:** Continuous monitoring of protected forest areas
- **Railway Track Monitoring:** Detecting animals on railway tracks to prevent collisions
- **Smart Agriculture Monitoring:** Protecting crops from wildlife damage
- **Disaster Management and Rescue Operations:** Locating fire-affected areas and trapped animals
- **Border Security:** Monitoring sensitive areas for unauthorized intrusion
- **Wildlife Conservation:** Tracking and monitoring endangered species

XI. CONCLUSION

The researchers have successfully developed an autonomous drone that can detect human intruders and animals, as well as detect objects and fire hazards in order to provide information to the authorities. The system includes safety mechanisms to observe those entering the surveillance area. The autonomous drone can assess situations and notify relevant officers with clear and accurate information for planning, tracking, and responding to incidents. This innovation enables officers to develop appropriate and timely solutions to current problems and events as they arise.

The integration of Edge AI with IoT technology has proven to be an effective approach for wildlife intrusion detection. The system's ability to process data locally on the drone reduces latency, conserves bandwidth, and enables operation in areas with limited internet connectivity. The use of a computationally efficient detection algorithm ensures that the system can run on resource-constrained embedded devices without compromising accuracy.

Future work will focus on improving battery life, expanding the dataset for more animal species, implementing swarm intelligence for multiple drone coordination, and integrating thermal imaging for night-time operation. Additionally, we plan to explore the use of TinyML models to further reduce power consumption and enable even more efficient edge processing.

XII. ACKNOWLEDGMENT

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