Project Phase II Report On

SkySentry : Unmanned Aerial Systems for Fire Detection and Suppression in Open Environments

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CERTIFICATE

This is to certify that the project report entitled ***"SkySentry : Unmanned Aerial Systems for Fire Detection and Suppression in Open Environments"*** *is a bonafide record of the work done by* ***Mr. Joel Joesph Justin (U2003105), Mr. Jonathan Antony (U2003108), Mr. Justin Joshy (U2003114), Mr. Krishnadas Balachandran (U2003121)****, submitted to the Rajagiri School of Engineering & Technology (RSET) (Autonomous) in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology (B. Tech.) in Computer Science and Engineering during the academic year 2023-2024.*

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Abstract

The proposed system aims to enhance fire detection and suppression capabilities in landfills using an integrated solution. A surveillance drone equipped with infrared imaging technology continuously monitors the landfill area for potential fire outbreaks. When a temperature spike indicative of a fire is detected, an alert is transmitted to the suppression drones. These drones autonomously navigate to the coordinates of the potential fire, verify the presence of fire, and if confirmed, deploy fire suppressants (Aqueous Film-Forming Foam - AFFF Balls) to mitigate the impact of fire. This system offers a rapid and efficient response to landfill fires while minimizing false alarms through autonomous navigation and fire verification processes.

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List of Abbreviations

UAV - Unmanned Aerial Vehicles

D2D - Device 2 Device

TDD - Time Division Duplex

CNN - Convolutional Neural Network

CCTV - Closed-Circuit television

GPU - Graphics Processing Unit

RAM - Random Access Memory

IoT - Internet of Things

PSO - Particle Swarm Optimisation

LoS - Line of Sight

AFFF Balls - Aqueous Film Forming Balls

IR - Infrared

IoU - Intersection over Union

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Chapter 1

Introduction

1.1 Background

The coastal Indian town of Kochi faced a hazardous situation when a fire erupted on March 2, 2023 at the Brahmapuram waste management plant. This resulted in the city being enveloped with a blanket of toxic fumes. The severity of the situation led to the closure of schools and colleges until March 15, 2023. A dedicated team of over 200 firefighters tirelessly battled the blaze, employing round-the-clock efforts to extinguish it. Using excavators, they dug 4-feet deep pits, into which 40,000 liters of water per second were sprayed in an attempt to quell the flames. Despite their concerted efforts, the fire was only fully contained 11 days after its ignition, with the lingering issue of smoke continuing to pose challenges for the community.

Figure 1.1: Firefighting operations being carried out at Brahmapuram waste treatment plant in Koch, courtesy of CNBCTV 18

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1.2 Problem Definition

This project aims to address the critical challenge of timely and efficient wildfire detection and suppression, leveraging the capabilities of Unmanned Aerial Vehicles (UAVs). Wildfires pose significant threats to ecosystems, human lives, and property, and the traditional methods of monitoring and combating them often face limitations in terms of speed and effectiveness. The primary problem this project seeks to tackle is the need for a more proactive and technologically advanced approach to wildfire management. The inherent dangers associated with wildfires, including their rapid spread and the difficulty of accessing remote or hazardous areas, make the use of autonomous UAVs an attractive solution to improve the speed and precision of detection and suppression efforts.

The identified problem can be characterized by the existing reliance on ground-based methods for fire detection, which may result in delays and limitations in coverage. Additionally, manual suppression efforts can be hazardous for firefighting personnel and may not be timely enough to prevent the escalation of wildfires. By introducing a dual UAV system with specialized roles for detection and suppression, the project seeks to mitigate these challenges. In essence, the problem at hand involves improving the overall responsiveness and effectiveness of wildfire management through the innovative use of UAV technology.

1.3 Scope and Motivation

This project focuses on developing a dual Unmanned Aerial Vehicle (UAV) system dedicated to wildfire detection and suppression. The scope includes the design, integration, and testing of two UAV platforms, each equipped with specialized sensors. The detection UAV autonomously scans designated areas using infrared sensors and image processing for fire and obstacle detection, while the suppression UAV navigates to identified fire locations and autonomously deploys a suitable retardant. The project also involves developing communication protocols for real-time data exchange between UAVs and evaluating the operational feasibility and scalability of the proposed system.

The motivation behind this endeavor arises from the urgent need for more effective wildfire management. Traditional methods, often reliant on ground-based personnel, face challenges in response time, accessibility, and safety. By harnessing advancements in UAV technology, the project seeks to create a proactive and autonomous solution that swiftly detects and suppresses wildfires. The integration of infrared sensors and cameras addresses the limitations of conventional detection, and autonomous suppression capabilities aim to improve the success rate of firefighting missions, contributing to the protection of ecosystems, human lives, and property. The project's overarching motivation is to leverage technology for innovative and impactful disaster response, aligning with broader goals of environmental conservation and efficient emergency management.

1.4 Objectives

- Implement an automated fire detection and suppression system using drones.
- Design and construct two specialized UAVs, one for detection and the other for suppression, each equipped with the necessary sensors and systems (infrared sensors, cameras, and suppression mechanisms) for their designated roles.
- Establish robust communication protocols between detection and suppression UAVs to facilitate real-time data exchange. This includes relaying information about fire location, intensity, and obstacle avoidance from the detection UAV to the suppression UAV.
- Conduct comprehensive flight tests to validate the performance and reliability of the dual UAV system in real world conditions. Gather data on the system's effectiveness in detecting and suppressing fires, obstacle avoidance, and overall mission success.
- Explore the possibilities of integrating the developed UAV system with existing wildfire management frameworks and emergency response systems. Ensure compatibility and collaboration with established protocols for a more comprehensive approach to wildfire management.

1.5 Challenges

- Navigating Regulatory Approval: Securing regulatory approval for the deployment of autonomous UAVs in wildfire management involves navigating complex airspace regulations and addressing safety and privacy concerns. The challenge lies in ensuring compliance with evolving regulatory standards and gaining acceptance for the innovative use of UAV technology in emergency response.

- Financial constraints: The project may face financial challenges related to the development, testing and deployment of a dual UAV system. Securing funding for advanced technologies, extensive testing, and operational scalability poses a hurdle that requires strategic resource allocation and potentially seeks collaboration with relevant stakeholders to overcome financial constraints.

- Drones malfunctioning after repeated testing: Repeated testing of UAVs in challenging and dynamic wildfire environments may lead to wear and tear, potential technical failures, or unexpected failures. Addressing the reliability and robustness of the UAV platforms is crucial to ensure consistent performance, requiring comprehensive analysis of failure modes, regular maintenance, and the implementation of effective redundancy measures.

- Technical Integration: Ensure seamless integration of multiple technologies, including infrared sensors, image processing, and suppression mechanisms, on both UAV platforms. Overcoming compatibility issues and optimizing the synchronization of these components for effective and reliable operation.

1.6 Assumptions

- Communication Infrastructure: The availability of reliable communication infrastructure for drone control and data transmission is assumed. Connectivity issues can impact the project.

- Regulatory bodies will provide necessary approvals for drone operations in firefighting scenarios.

1.7 Societal Relevance

The implementation of an advanced drone-based wildfire management system, incorporating a two-drone approach for early detection and rapid suppression, holds immense societal benefits. This innovative system enhances public safety by autonomously detecting initial signs of fire, such as temperature spikes or smoke, and promptly relaying precise coordinates to suppression drones. The streamlined response not only minimizes the potential escalation of wildfires but also optimizes the allocation of firefighting resources, contributing to efficient and cost-effective wildfire management. The system's autonomous capabilities enhance the safety of first responders by reducing direct exposure to hazardous environments. Furthermore, by preventing the spread of fires and minimizing environmental impact, the drone-based approach serves as a crucial tool in protecting communities, infrastructure, and natural habitats. In essence, this application represents a pioneering step toward leveraging cutting-edge technology for sustainable wildfire prevention and containment, aligning with the evolving needs of society in addressing critical challenges.

1.8 Organization of the Report

The report is organised into 5 chapters, beginning with the introduction in chapter 1. This gives us the Background for which we are undertaking this project. A brief problem definition is given followed by the scope and motivation of the project. The objectives the project aims to accomplish along with potential challenges that could be faced are also discussed in this chapter.

Chapter 2 gives a literature survey where few papers regarding the existing technologies related to the project are discussed. A few research gaps related to the papers are also discussed here.

Chapter 3 deals with the Hardware and Software Requirements for the project.

Chapter 4 gives an overview of the working of the system. It gives us the architectural design and a module division. A brief description of each module is provided followed by the division of responsibilities among the team members. A work schedule of the project is also given.

The report concludes with Chapter 5, which discusses the future scope of the project

Chapter 2

Literature Survey

2.1 Multi-UAV Collaboration for Fire Detection and Suppression, Andrew Moffatt *et al.*, 2021

2.2 Introduction

The paper "Collaboration between Multiple UAVs for Fire Detection and Suppression" by Andrew Moffatt *et al.* [5] proposes method which will effectively help in combating uncontrolled wildfires is crucial for safeguarding lives and property. Traditional methods such as ground-based systems, satellite, and manned aircraft remote sensing have limitations in terms of range, cost, and safety. This paper explores the use of Unmanned Aerial Vehicles (UAVs) equipped with infrared cameras for autonomous fire detection and suppression. Multiple UAVs are employed to cover large areas efficiently, reducing risks to firefighters and addressing manpower shortages during large fires. The first UAV autonomously locates fires using an infrared camera, and the information is relayed to a second UAV, which suppresses the flames autonomously. Additionally, the paper discusses the use of sense-and-avoid and path planning techniques for fire detection and suppression in urban and residential areas. The organization of the paper includes sections on hardware components, flight planning algorithms, simulation, methods for fire detection, determination of fire location, and flight test results, concluding with insights into future work in this field.

2.2.1 Methodology

It mentions the use of an Intel NUC processor as a flight computer, which is responsible for processing a large volume of information received from the LiDAR and the inertial measurement unit (IMU). The Intel NUC processor also handles the obstacle avoidance algorithm. Additionally, the paper mentions the use of an FLIR TAU thermal camera for infrared sensing, which is crucial for fire detection. The hardware components play a vital role in the successful operation of the UAVs for fire detection and suppression.

A fire detection algorithm was developed using a thermal camera, consisting of preprocessing and heat source identification components. The preprocessing involves applying an intensity brightening operation (IBO) to enhance the image and remove background and noise. The heat sources are identified by finding the maximum, creating a binary image, and applying an area filter. The algorithm for determining if the heat sources are actual fires is still being investigated, but may involve signatures, wavelet decomposition, and intensity saturation. After fire detection, the geolocation of hot spots is determined using a real-time direct georeferencing process. The NED coordinates of the hot spots are computed using camera intrinsic matrix, pixel positions, and transformation matrices. The position of the fire is relayed back to the suppression UAV using GPS coordinates. The FLIR Tau thermal camera's isotherms feature is used to add color to pixels in a certain thermal range to help identify fires. DroneKit, an open-source library, is used for flight control software to navigate the detection UAV in a hazardous environment. DroneKit-SITL simulation allows for testing applications on a virtual UAV before real flight, decreasing costs and increasing success rates. The primary path planning algorithm uses an edge detection method for obstacle avoidance. An additional obstacle avoidance algorithm scans for moving obstacles and changes in the environment to maintain obstacle avoidance capabilities. The algorithm communicates a change of velocity to the UAV and initiates a brief delay to move away from nearby obstacles. The overall complexity of the georeference algorithm depends on the complexity of obtaining pixel positions of hot spots using object detection's algorithm. Integration of the algorithm with DJI's A3 software development kits will be done in the future.

2.3 Collision Avoidance Strategy with D2D Communications, Shan *et al.*, 2023

2.3.1 Introduction

The paper "A novel collision avoidance strategy with d2d communications for uav systems" by Shan *et al.* [3] proposes a distributed collision avoidance system based on D2D communication. It achieves this by sharing relevant information like velocity, position and radius of alert sphere, based on which the drones can judge if a collision will occur or not. This information is communicated between the Drones and does not involve any Centralized Control System. If it detects a collision, it can take corrective action by changing it's velocity.

2.3.2 Methodology

Each UAV in the area is assumed to travel with a velocity, position, and has an alert sphere of radius R. The drones communicate this information with other drones in the are by establishing a D2D Time Division Duplex(TDD) communication channel with each other. The radius is calculated based on the velocity of the drone and the response time that it takes for the drone to take an action after it receives a signal. Based on the radius of the alert sphere and the information, such as position, that is received from other drones, they decide if any collision will occur. This is done by checking if there is any intrusion between the alert spheres of a given drone and other drones in the area. A collision is said to have occurred if the distance between the drones at a given time is less than the sum of the radii of the given drones. When a drone detects a collision may occur, the drones change the velocity in order to avoid the collision.
An additional weighting parameter is introduced to preserve the order of arrival of the drones at their desired destination.

2.3.3 Advantages

- This method reduces the dependence of the drone on centralized hardware.
- Preserves order of arrival of drones at the destination.

2.3.4 Disadvantages

- This method is not able to avoid collision with objects that are unable to communicate with the drone. Drones require other hardware like cameras to detect these obstacles and take avoidance action.
- The efficacy of this method depends on the time interval between consecutive data transmission. A greater time interval means the drone travel a greater distance

before getting updated information. If the time interval is too small, then the drone does not have enough time to run the computations and calculate if a collision has occurred.

2.4 EdgeFireSmoke: Real-Time Fire–Smoke Detection with Lightweight CNN, J. S. Almeida *et al*, 2022

2.4.1 Introduction

The paper "EdgeFireSmoke: A Novel Lightweight CNN Model for Real-Time Video Fire–Smoke Detection" by J. S. Almeida *al.*[2] proposes a new method based on deep learning techniques using CCTV cameras and UAV aerial photographs is proposed for immediate detection of forest fires and smoke. The proposed EdgeFireSmoke method is a lightweight CNN architecture that reduces detection time and GPU memory consumption without significant loss of performance. The EdgeFireSmoke method can be integrated with CCTV systems and UAV inspections, providing real-time detection of fire points in monitored regions. The method has greater accuracy and shorter detection time compared to existing methods, while requiring less memory and energy.

2.4.2 Methodology

The study employs two datasets: Dataset 1 (CCTV Images of Smoke) and Dataset 2 (UAV Images of Wildfires). Dataset 1 contains 72,012 CCTV images categorized into four classes, with resolutions of 352x288 pixels. Dataset 2, derived from public UAV videos, comprises 49,452 samples categorized into burned-area, fire-smoke, fog-area, and green-area classes. Both datasets were used to train and assess a lightweight CNN model for real-time video fire-smoke detection, designed for edge devices with a minimum of 1 GB RAM. The model optimally utilizes two convolutional layers with 32 filters each, followed by max pooling layers and a dense neural network. Evaluation was conducted in forest observation towers with CCTV systems and aerial UAV images. The proposed model, with minimal parameters, can send alerts for real-time fire-smoke detection, providing the incident's exact location via radio communication. Training involved preprocessing steps of image normalization and resizing to 224x224 pixels. The CNN model, termed EdgeFireSmoke, demonstrated effectiveness in experiments with ten epochs and a learning rate of 0.001, outperforming other methods that used transfer learning and fine-tuning. The study emphasizes the model's application in diverse environments and its potential for IoT-based alert systems. The proposed method achieved an accuracy of 98.71% and an F1-score of 98.97% in Dataset 1, with the smallest loss compared to other methods. In Dataset 2, the proposed method achieved an accuracy of 95.77% and a precision of 96.25%.

2.5 A privacy preserving IoT based fire detector, A. H. Altowaijri *et al.*, 2021

2.5.1 Introduction

The increasing reliance on Internet of Things (IoT) devices for fire detection has brought forth a critical concern—privacy. In this context, the paper 'A privacy preserving IoT based fire detector' by A. H. Altowaijri *et al.* [4] addresses the paramount need for a fire detection system that not only harnesses the capabilities of IoT devices but also prioritizes the preservation of privacy in surveillance. Focusing on the challenge of maintaining a delicate balance between accurate fire detection and safeguarding the privacy of the monitored surroundings, our research proposes an innovative solution. Leveraging cloud-based processing, the system sends extracted video features instead of raw footage to mitigate privacy threats. The combination of binary video descriptors and Convolutional Neural Network (CNN) forms the backbone of our fire detection algorithm, achieving a remarkable classification accuracy of 97.5%. This breakthrough not only ensures a reliable fire detection system but also establishes a privacy-preserving capability, marking a significant stride in the evolution of fire detection technologies.

2.5.2 Methodology

Our methodology revolves around developing a privacy-preserving IoT-based fire detector, harmonizing advanced technological components for efficient and secure fire detection. The system utilizes IoT devices equipped with cameras for video surveillance. The captured videos undergo feature extraction through binary video descriptors, capturing essential characteristics while bypassing raw footage transmission to the cloud. This privacy-focused approach mitigates the risk of unauthorized access or privacy violations associated with cloud-based systems. The extracted features are then processed by a Convolutional Neural Network (CNN), a deep learning architecture renowned for its prowess in image classification tasks. This integration allows accurate fire detection while preserving the privacy of the monitored environment. Extensive experimentation, using real fire and non-fire scenes, validates the proposed algorithm's exceptional performance, achieving a classification accuracy of 97.5%. The implementation is also optimized for real-time processing on resource-constrained IoT devices, exemplified by the Raspberry Pi 4 platform, ensuring practical applicability and efficiency in various surveillance scenarios.

2.6 Autonomous UAV Path Planning Using Modified PSO for UAV-Assisted Wireless Networks, Amala Sonny *et al*, 2023

2.6.1 Introduction

This paper [1] by Amala Sonny *et al.* introduces a novel approach to optimizing the path planning of Unmanned Aerial Vehicles (UAVs) using a modified Particle Swarm Optimization (PSO) algorithm. The first objective is to increase the efficiency and reliability of UAV navigation from a starting position to a target location to avoid obstacles. The enhancements to the PSO algorithm proposed in this paper take into account Line of Sight (LoS) communication with the user and seek to establish a guaranteed communication rate. The paper assesses the performance of the novel method in various situations, and its performance is compared with previous ones using energy usage, distance covered, and travel time as a metric. The simulation results confirm the efficiency of the suggested solution to optimize the planning of the UAV path and improve the reliability of the communication.

2.6.2 Methodology

The proposed methodology in this paper revolves around a tailored Particle Swarm Optimization (PSO) algorithm designed for optimizing the path planning of Unmanned Aerial Vehicles (UAVs). In the context of UAV navigation, the PSO algorithm is employed to iteratively update the positions and velocities of simulated particles, each representing a potential path from the UAV's starting point to its target destination while avoiding obstacles. A critical aspect of the proposed modification is the integration of line-of-sight

(LoS) considerations, ensuring that the UAV maintains a reliable communication link with the user throughout its journey. This is achieved by evaluating the LoS probability at each iteration and adjusting the path accordingly to meet required communication rates. The algorithm undergoes iterations, dynamically updating the UAV's position and velocity based on the best solutions found by individual particles and the swarm as a whole. The performance of the algorithm is thoroughly tested and evaluated in terms of energy consumption, distance traveled, and travel time, showcasing its effectiveness in optimizing the planning of the UAV path and ensuring reliable communication with the user.

2.6.3 Advantages

The paper introduces a novel Particle Swarm Optimization (PSO) algorithm for UAV path planning, significantly improving efficiency across various scenarios. In particular, the algorithm dynamically optimizes UAV trajectories, reducing energy consumption, travel distance, and time while ensuring uninterrupted communication with the user through Line of Sight (LoS) probability considerations. The proposed methodology exhibits adaptability across three scenarios: 2D path planning, 3D navigation from ground to sky, and obstacle-laden environments. Its versatility is a key strength that demonstrates its effectiveness in diverse operating conditions. In addition to its adaptability, the PSO algorithm outperforms existing methods in key performance metrics. Through comprehensive experiments, the paper establishes the algorithm's superiority in terms of energy consumption, distance traveled, and travel time. Moreover, scenario-specific adaptations, such as obstacle avoidance, enhance the algorithm's robustness, making it a valuable contribution to UAV optimization research. Overall, the proposed methodology presents a comprehensive solution, combining innovative optimization techniques with practical considerations for real-world UAV applications.

2.6.4 Disadvantages

While the proposed Particle Swarm Optimization (PSO) algorithm for UAV path planning demonstrates significant advantages, one potential limitation is its sensitivity to parameter settings. The algorithm relies on parameters such as inertia weight, learning factors, and maximum velocity, which need careful tuning for optimal performance. In real-world applications, finding the right combination of these parameters might pose a challenge and could affect the algorithm's effectiveness. Sensitivity to parameter settings can lead to suboptimal results or difficulties in achieving consistent performance across various scenarios. Therefore, a potential disadvantage lies in the need for fine-tuning parameters to ensure the algorithm's robustness and applicability to diverse environments.

2.7 Summary and Gaps Identified

The literature survey encompasses various papers addressing critical aspects of UAV-based applications, including fire detection, collision avoidance, privacy-preserving IoT fire detection, lightweight CNN models for real-time fire-smoke detection, and UAV path planning using modified PSO. Moffatt et al.'s work introduces a multi-UAV collaboration for efficient fire detection and suppression. The collision avoidance strategy by Shan et al. utilizes D2D communication for distributed drone collision prevention. Almeida et al. propose EdgeFireSmoke, a lightweight CNN model for real-time fire-smoke detection, showcasing improved accuracy and reduced memory consumption. Waijri's privacy-preserving IoT fire detector emphasizes a balance between accurate fire detection and privacy preservation. Sonny et al.'s paper introduces a modified PSO algorithm for optimizing UAV path planning, enhancing efficiency and reliability. While the PSO algorithm shows promise, a potential drawback lies in its sensitivity to parameter settings, requiring careful tuning for optimal performance. Overall, these papers collectively contribute to advancing UAV-based technologies for diverse applications, addressing challenges and presenting innovative solutions.

Table 2.1: Advantages and Disadvantages of paper by A.Sonny *et al.* [1]

Paper Title	**Advantages**	**Disadvantages**
Autonomous UAV Path Planning Using Modified PSO for UAV-Assisted Wireless Networks	• Optimizes UAV paths, reducing energy consumption, distance, and travel time. • Incorporates LoS probability for effective communication with users, ensuring required data rates. • Demonstrates adaptability across 2D and 3D environments with and without obstacles. • Leverages swarm behavior for optimal path exploration, suitable for autonomous navigation.	• Susceptible to parameter variations, requiring careful tuning. • Evaluated in specific scenarios; may require further validation in diverse environments. • Convergence effectiveness varies, with the algorithm showing better results over increased iterations.

Table 2.2: Advantages and Disadvantages of paper by J. S. Almeida *et al.* [2]

Paper Title	**Advantages**	**Disadvantages**
EdgeFireSmoke: A Novel Lightweight CNN Model for Real-Time Video Fire–Smoke Detection	• Proposed CNN model has lower computational cost and classification time. • Proposed CNN model requires less RAM compared to other evaluated methods. • Proposed CNN model has advantages in terms of energy consumption during testing phase.	• Filters in deep learning models are limited to daytime operations. • The proposed system does not need expensive cameras but only limited any RGB cameras. • Synthetic Hazy image dataset used for smoke detection.

Table 2.3: Advantages and Disadvantages of paper by Shan *et al.* [3]

Paper Title	**Advantages**	**Disadvantages**
A Novel Collision Avoidance Strategy with D2D Communications for UAV Systems	• This method reduces the dependence of the drone on centralized hardware. • Preserves order of arrival of drones at the destination.	• Method lacks built-in collision avoidance, relies on external hardware like cameras for detecting and avoiding obstacles. • Method effectiveness hinges on data transmission intervals; longer intervals result in outdated information, risking delayed collision awareness, while overly short intervals impede real-time computations for collision assessment.

Table 2.4: Advantages and Disadvantages of paper by Abdullah H. Altowaijri *et al.* [4]

Paper Title	**Advantages**	**Disadvantages**
A privacy preserving IoT based fire detector	• Ensures privacy by sending only feature-extracted data to the cloud, mitigating traditional surveillance privacy concerns. • Applicable in diverse scenarios, especially sensitive environments, and adaptable to uncertain conditions like smoke or fog. • Optimized for real-time processing on resource-constrained IoT devices, making it practical for various settings.	• Relies on internet connectivity for cloud processing, potentially impacting effectiveness in low or no connectivity scenarios. • The integration of binary video descriptors and CNN adds complexity, requiring careful maintenance and troubleshooting. • Transmission and processing may introduce latency, affecting responsiveness in time-sensitive situations.

Chapter 3

Requirements

3.1 Hardware and Software Requirements

3.1.1 Hardware Requirements

- Drone Kit
  - 1 x Radiolink Pixhawk Flight controller board
  - 1 x DJI F450 Quadcopter Frame Kit
  - 4 x A2212 1000KV Brushless Motor For RC Airplane / Quadcopter
  - 4 x 30A Brushless ESC
  - 2 x 1045 Propeller 10in 10x4.5 For Drone
  - 1 xFlysky FS-i6S 2.4G 10CH AFHDS Transmitter With FS-iA10B 10CH Receiver
  - 1 x APM Pixhawk Power Module with XT60
  - 1 x Nylon Strap Belt for RC Lipo Battery
  - 1 x 3D printed Shock Absorber Anti-vibration Set for APM Pixhawk
  - 1 x Pixhawk V2.4.8 Flight board with Original Shell.
  - 3 x Connecting Cables
  - 1 x Buzzer Module
  - 1 x Glass Fiber Flight Controller Anti-vibration/Shock absorber Set.
  - 1 x NEO-M8N GPS Module with translucent shell.
  - 1 x GPS Folding Base Antenna set.
  - 1 x APM 2.5.2/2.6/2.8 Pixhawk Power Module.

- Camera
  - 1 x Raspberry Pi Infrared IR Night Vision Surveillance Camera
  - Raspberry Pi Camera Cable
- Single Board Computer
  - Raspberry Pi 4 Model 4GB
- Desktop with specification:
  - Processor AMD Ryzen 5 4600H with Radeon Graphics 3.00 GHz
  - Installed RAM 16.0 GB

3.1.2 Software Requirements

- Python 3.10
- OpenCV 4.8.0
- Tensorflow 2.14
- YOLO v5
- Pytorch 2.1.2

Chapter 4

System Architecture

4.1 Introduction

In this section, We delve into the system overview, exploring its implementation and key considerations. The architecture diagram, module division, and delineation of responsibilities provide a comprehensive view of our innovative fire detection and suppression system. The modular structure ensures efficient collaboration between Communication, Path Planning, and Fire Detection modules, each contributing uniquely to the system's seamless operation. The division of responsibilities underscores a collaborative and effective workflow. This introduction offers insights into our holistic approach, combining technological prowess and modular design to create a robust fire protection system.

4.2 System Overview

The comprehensive fire detection and suppression system is deployed utilizing two specialized drones: a surveillance drone dedicated to monitoring and a suppression drone designed for immediate suppression of the fire. The surveillance drone systematically traverses the targeted open areas,forest areas or wasteland area , employing integrated cameras to meticulously scan sections for any indications of heightened temperature or the presence of smoke, indicative of an initial fire outbreak.

Upon detecting a potential fire, the surveillance drone promptly relays precise coordinates to the suppression drones stationed at the docking station. The suppression drones swiftly respond to the provided coordinates and employ advanced IR thermal cameras, along with a sophisticated fire detection module, to validate the presence of fire. In the event of a confirmed fire, the suppression drones alert first responders and initiate a prompt and controlled fire suppression mechanism. This involves the strategic deployment of Aqueous Film Forming Foam (AFFF) balls onto the fire, effectively containing and mitigating the incident.

The fire suppression mechanism continues until either the arrival of professional fire-fighters or the complete extinguishment of the fire. In case of a false alarm, the suppression drones autonomously return to the docking station, ensuring efficient resource utilization and readiness for subsequent operations. This integrated drone-based system enhances early detection, rapid response, and effective fire suppression, contributing to the overall safety and protection of targeted areas.

4.3 Architectural Design

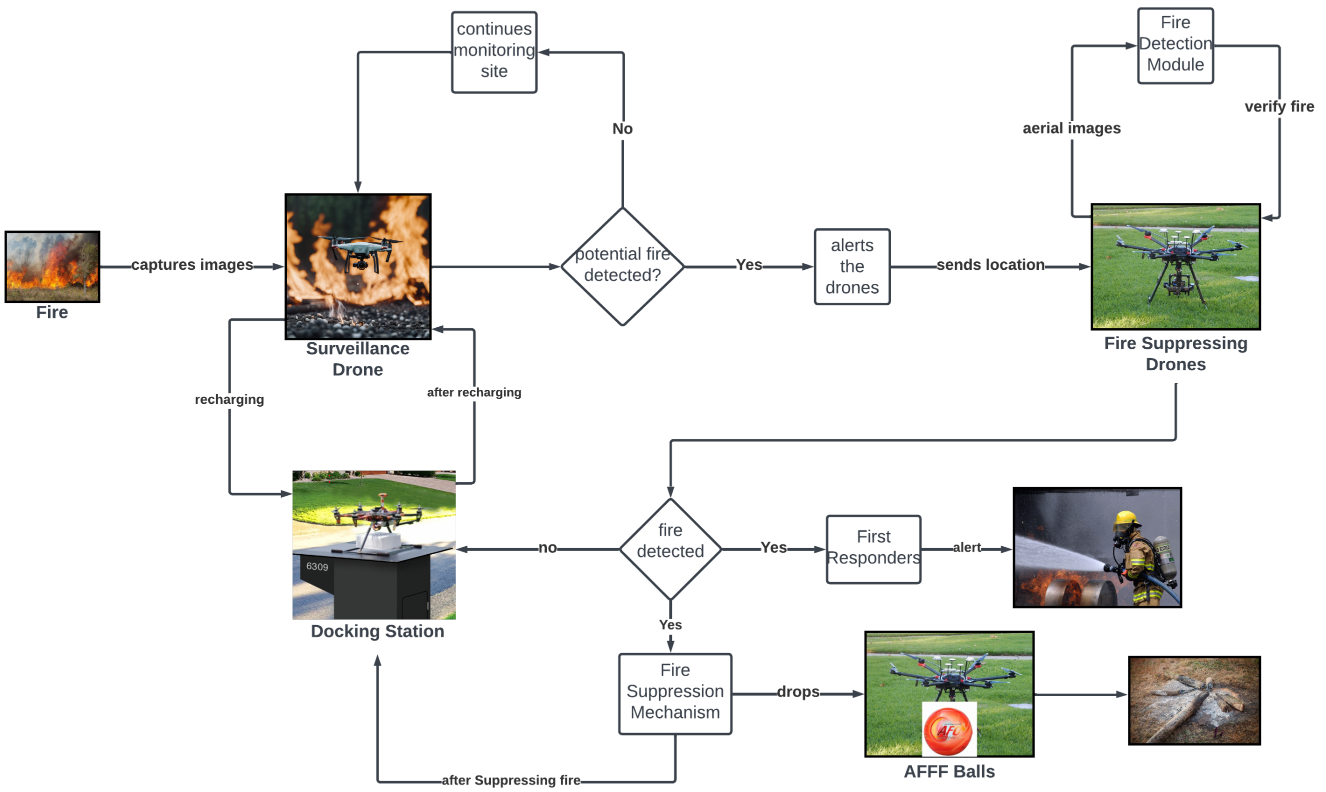

Figure 4.1: Architecture Diagram.

4.4 Module Division

1. Communication Module
2. Path Planning and Collision Avoidance Module:
3. Fire Detection Module:

4.4.1 Modules

- Communication Module
  - The Communication Module facilitates seamless communication both between drones and between drones and a central server. This includes the reception of frames from surveillance drones, enabling the transmission of signals along with GPS coordinates to secondary drones, and the dissemination of alerts alongside corresponding GPS coordinates to first responders.
- Path planning
  - The Path Planning and Collision Avoidance Module are pivotal for ensuring efficient navigation and safety in drone operations. It encompasses path planning algorithms, such as Particle Swarm Optimization (PSO), to chart optimal routes for drones. Moreover, it incorporates collision avoidance mechanisms to prevent potential conflicts with obstacles or other drones during flight.
- Fire Detection
  - The Fire Detection Module serves the critical function of identifying and responding to fire incidents. It comprises two primary components:
  - Primary Detection:
    * This aspect involves receiving frame inputs from surveillance drones and employing temperature variance analysis techniques, such as thresholding, to detect potential fire outbreaks. It returns a true indication if a fire is detected based on predefined thresholds.

- Secondary Detection:
  * Here, the module receives frame inputs from secondary drones and employs advanced deep learning techniques, specifically YOLO Convolutional Neural Networks (CNNs), to detect fires with higher precision. Similar to primary detection, it returns a true indication if a fire is detected, thus providing redundant fire detection capabilities for enhanced reliability.

4.4.2 Division of Responsibilities

- Krishnadas Balachandran - Fire detection, Collision avoidance, Communication
- Jonathan Antony - Communication, Autonomous navigation
- Justin Joshy - Hardware, Obstacle detection, Fire Detection
- Joel Joseph Justin - Drone Procurement, Path Planning, Collision Avoidance

4.5 Work Schedule - Gantt Chart

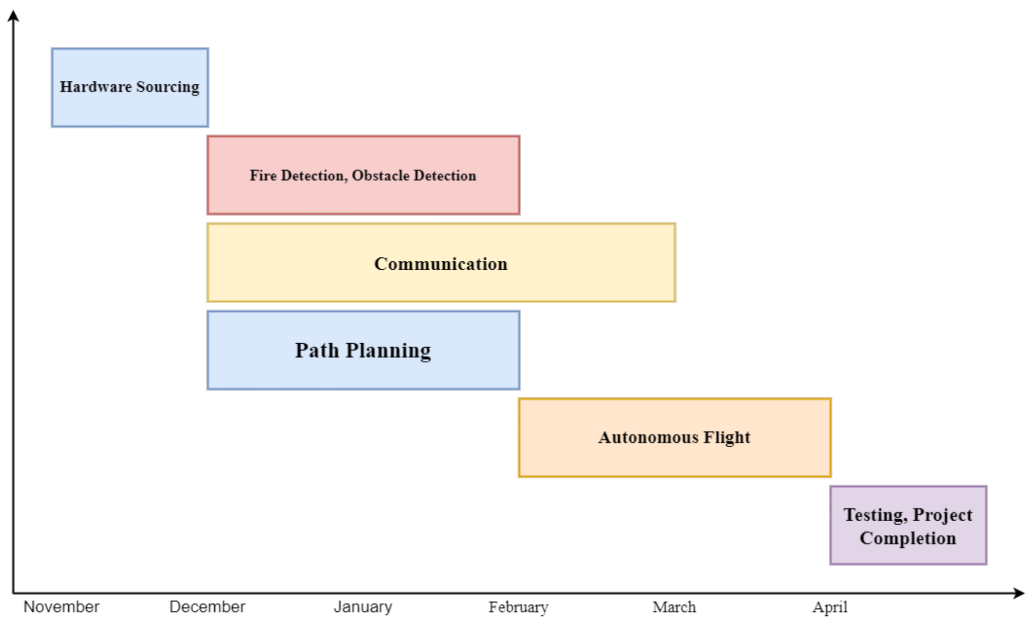

Figure 4.2: Gantt Chart

4.6 Chapter summary

This chapter unfolds the intricacies of the fire detection and suppression system. Beginning with a detailed system overview, we explore the thoughtful implementation, considering critical factors. The architecture diagram visually captures the essence of our innovative solution. Module division outlines the roles of Communication, Path Planning, and Fire Detection, ensuring a cohesive and efficient design. Responsibilities are distributed strategically, emphasizing collaboration. This chapter, a synthesis of technological innovation and modular precision, lays the foundation for a comprehensive fire protection system.

Chapter 5

System Implementation

5.1 Datasets Identified

The first dataset "Fire Dataset in Yolo Format" by Antro Safin was obtained through Kaggle and was used to train a model that can detect fire using an RGB camera. This dataset consists of 362 images of fire with labels for each of the images provided in YoLo format. The dataset split is given as:

- Training: 300 (70 %)
- Testing: 52 (20 %)
- Validation: 10 (10 %)

The second dataset "Infrared Fire Dataset" from Hanyang University [6] was obtained through Roboflow.com and was used to train a model that can detect hotspots through thermal IR cameras. The dataset consists of various images of fire taken using a thermal IR camera with labels for each images provided in YoLo format as a text file.

5.2 Proposed Methodology/Algorithms

The system uses Mission Planner software by Michael Oborne to select the waypoints and plan the mission. Once selected, these are sent to the UAV's flight controller. Once the flight controller receives the waypoint coordinates, it flies through those waypoints at the altitude specified. During this flight, the UAV collects video input using the onboard camera connected to a Raspberry Pi5, and sends this along with the GPS coordinates from the GPS module to a computer offsite.

The computer uses a YoLov5 model trained using the datasets mentioned earlier and detects any fire in the scene.

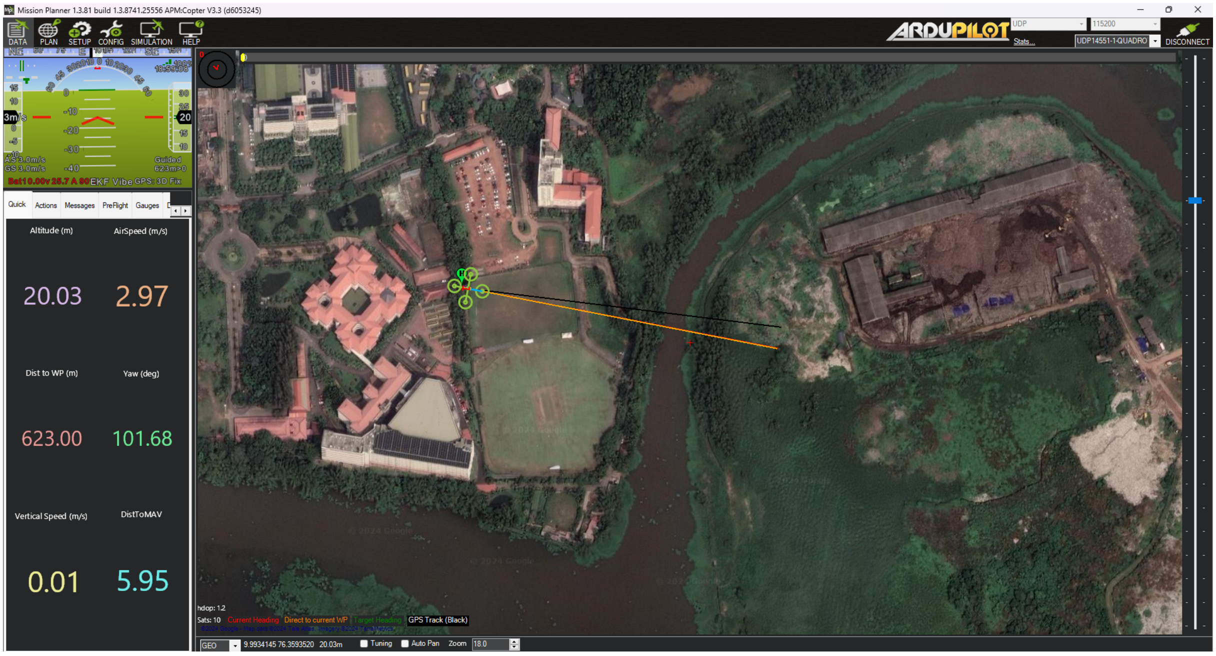

Figure 5.1: Mission Planner UI

5.3 User Interface Design

The User Interface is provided by the Mission Planner. This software allows us to easily plan the UAV's mission and see the technical stats in real time.

5.4 Description of Implementation Strategies

The Fire Detection model was trained using the specified Dataset in Python using YoLov5 in Google Colab. Once training was finished, the performance metrics of the model was automatically generated. The video input feed was captured using the OpenCV library in Python. This was sent to the off-site computer as frames through a TCP connection.

Chapter 6

Results and Discussions

In this section, We delve into the overview of the overall results achieved in terms of end results, quantitative results and finally the discussion on the summary of the results.

6.1 Overview

The proposed landfill fire detection and suppression system is a groundbreaking innovation that combines infrared camera monitoring and autonomous drones to revolutionize landfill fire management. Traditional methods often suffer from delayed response times, leading to extensive damage and environmental harm. However, this system promises to address these shortcomings effectively.

By integrating infrared camera monitoring, the system can swiftly detect even minor temperature fluctuations, allowing for early fire detection. This proactive approach enables faster response times, minimizing the spread and severity of fires. Additionally, the autonomous drones equipped with fire suppression capabilities can swiftly navigate the landfill terrain, reaching inaccessible areas quickly. This rapid intervention not only prevents fires from escalating but also reduces the environmental impact by limiting the release of harmful emissions and pollutants. Moreover, the system enhances safety for landfill operations by reducing the risk of firefighter exposure to hazardous conditions. By employing drones for fire suppression tasks, personnel can maintain a safe distance from the blaze while remotely guiding the drones to extinguish the fire. This minimizes the potential for injuries and ensures a more efficient firefighting process.

6.2 Testing

In order to ensure the efficacy and reliability of our fire detection and response system, rigorous testing was conducted across various stages of development. Below, we provide a comprehensive overview of the testing process along with images that illustrate key aspects of our testing procedures.

6.2.1 Fire detection

The initial stages of testing involved running our fire detection model on sample videos. The figure 5.1 depicts the model in action, detecting fires with high accuracy. This phase was crucial in assessing the model's performance and fine-tuning its parameters to optimize detection capabilities.

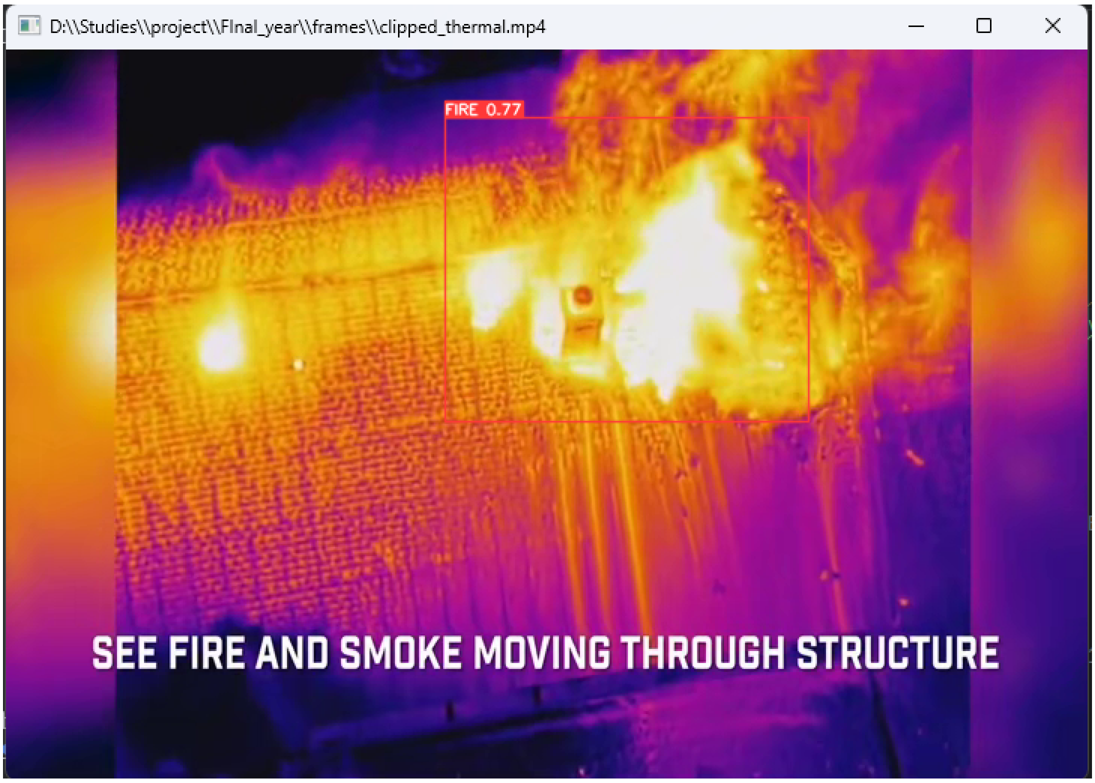

Figure 6.1: Fire detection model on a video sample

6.2.2 Validation with sample

Building upon the detection model's success, the figure 5.2 showcases the validation process using a sample video. Through meticulous testing, we verified the model's ability to accurately identify fires in real-world scenarios, thereby instilling confidence in its reliability for deployment.

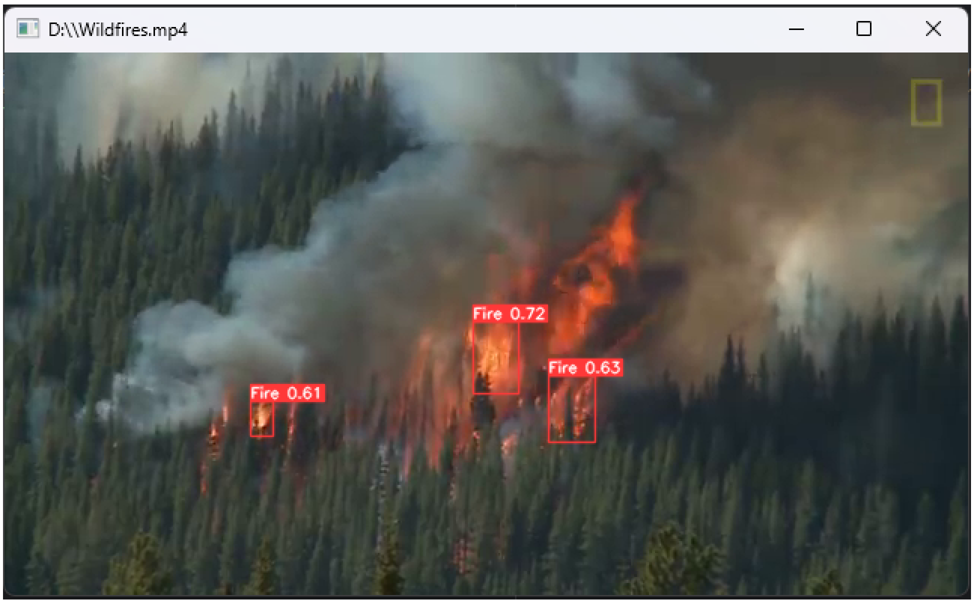

Figure 6.2: Fire detection model on a video sample

6.2.3 Graphical User Interface (GUI) for First Responders

Our system integrates a user-friendly GUI for first responders, as depicted in the third image. This interface facilitates seamless communication of crucial information, such as fire location and GPS coordinates, with the press of a button. This streamlined approach enhances the efficiency of emergency response efforts.

Figure 6.3: GUI showing location on map

6.2.4 Server-Client Communication

The figure 5.4 and 5.5 highlight the transmission of video frames from the server to the client. This communication infrastructure plays a pivotal role in ensuring timely delivery of visual data to the fire detection model for analysis, enabling swift detection and response to fire incidents.

Figure 6.4: Server sending video frames

Figure 6.5: Client recieving video frames

6.2.5 Mission Planning Software

Leveraging sophisticated mission planner software, as depicted in the figure 5.6, we meticulously script and select waypoints for drone missions. This strategic approach enables precise navigation and efficient coverage of target areas, optimizing the effectiveness of our fire response operations.

Figure 6.6: Scripting mission by establishing waypoints

6.2.6 Terminal Interface for Drone Communication

The figure 5.7 showcases the terminal interface used for drone communication, established through mavproxy. This vital component facilitates interaction with drones, enabling real-time monitoring and control essential for effective deployment in fire response missions. Through rigorous testing and validation at each stage of development, our fire detection and response system demonstrate robust performance and readiness for real-world deployment, bolstering emergency response capabilities and safeguarding communities against the threat of wildfires.

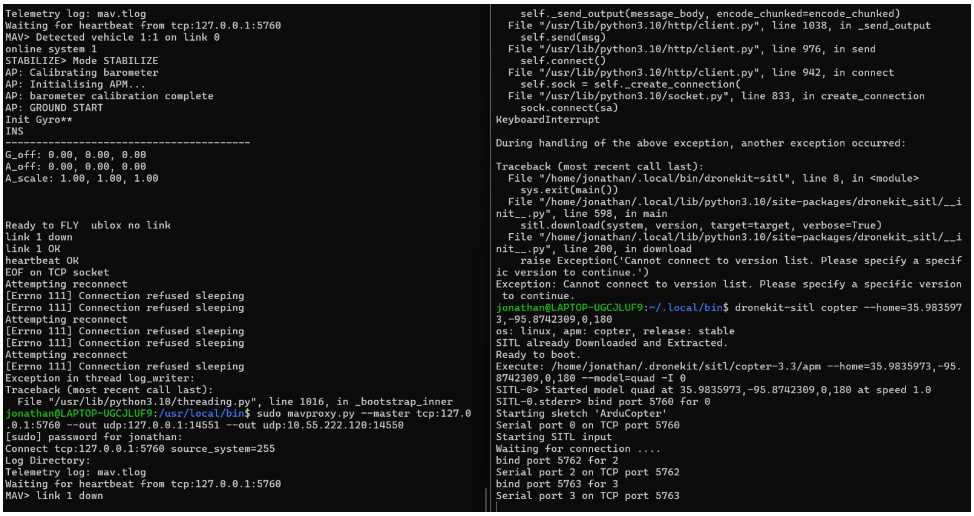

Figure 6.7: Terminal setting up drone communication

6.3 Quantitative Results

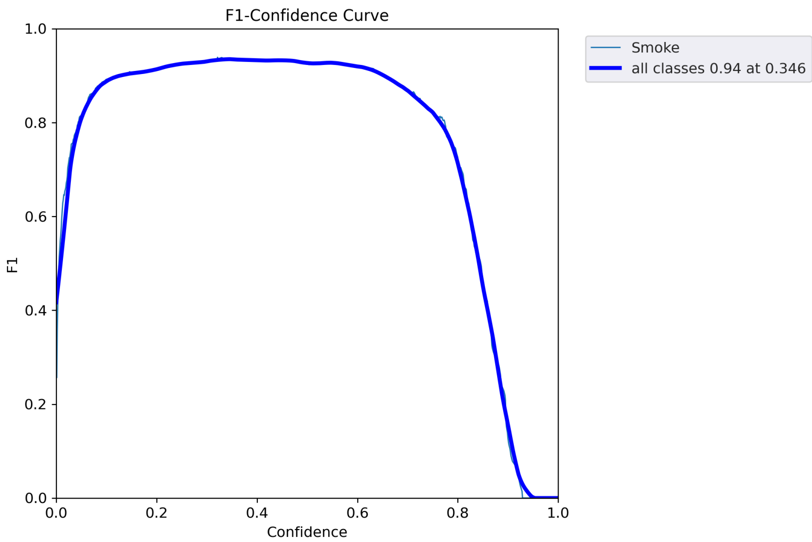

Figure 6.8: F1 Confidence Curve

The F1 score is calculated using the formula

$$F1 = 2 \times ((precision \times recall)/(precision + recall))$$

The F1-Confidence curve shows the relationship between the model's confidence in a prediction and the F1 score, a measure of model performance that considers both precision and recall. In the context of fire detection, precision refers to the proportion of detections that are actual fires, and recall refers to the proportion of actual fires that are detected by the model.

The F1-Confidence curve shows that as the model's confidence in a prediction increases, the F1 score also increases. This means that the model is more likely to be correct when it has high confidence in a prediction. The curve reaches a maximum F1 score of 0.94 at a confidence threshold of 0.346. This means that the model has the best balance of precision and recall when it predicts fires with a confidence greater than 0.346.

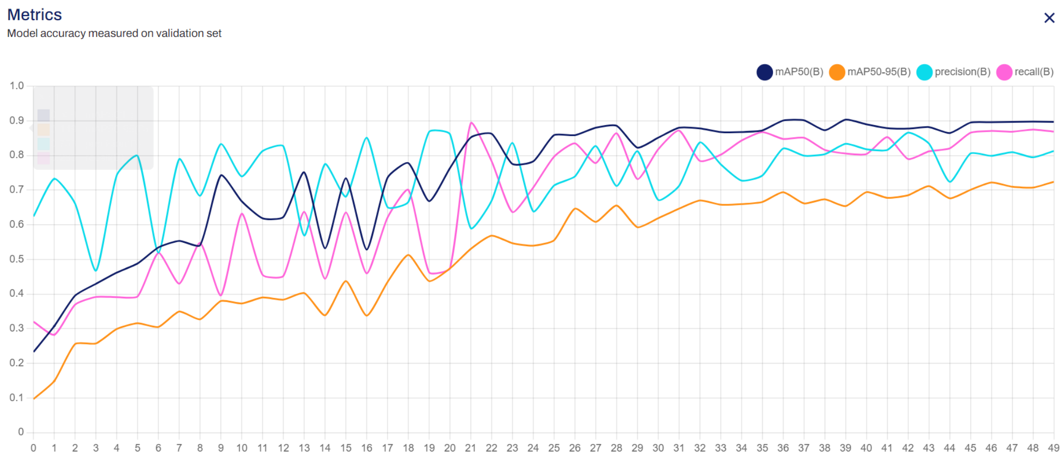

Figure 6.9: Performance metrics

1. mAP@0.5 (mean Average Precision at Intersection over Union(IoU) threshold at 50%): mAP@0.5 has the value 0.9. This indicates good overall detection performance. An mAP of 1 would be a perfect score, so 0.9 signifies the model can accurately detect fires with a good degree of overlap (IoU of at least 50%) between the predicted bounding box and the ground truth location in most cases.

2. mAP@0.5-0.95 (mean Average Precision at IoU between 0.5 and 0.95): The mAP@0.5-0.95 is 0.7. This is slightly lower than mAP@0.5, but still indicates acceptable performance. The model can find fires with a wide range of overlap (between 50% and 95%) between the predicted box and the actual fire location in a decent number of cases.

3. Recall of 0.85 is a relatively high value, indicating the model successfully identifies a good proportion of the actual fires in the test dataset.

4. The precision (0.8) being close to the recall (0.85) suggests a well-balanced model. It effectively identifies a good portion of actual fires (high recall) and most of those detections are indeed fires (high precision).

5. Based on these metrics, it can be concluded that the fire detection model appears to be functioning well. It has a good success rate at finding fires (high Recall) and can accurately localize fires with a significant degree of overlap between predicted and real locations (good mAP).

Figure 6.10: Box loss, Object Loss and Class loss

1. Box loss is a metric used in object detection models to measure the difference between the predicted bounding boxes and the ground truth boxes (actual locations of fires in the training data).A generally decreasing curve indicates the model is learning to predict bounding boxes that better match the ground truth fire locations. Ideally, the curve should flatten out at a low loss value in later epochs, signifying the model has converged and is no longer significantly improving its bounding box predictions.

2. The Class Loss curve plots the classification loss over the course of training. Classification loss measures how well the model can distinguish between fire and background in the images. A decreasing curve suggests the model is improving its ability to correctly classify fire pixels and background pixels. Similar to the box loss graph, ideally the curve should flatten out at a low loss value in later epochs, indicating the model has converged in terms of classification.

3. The Object loss curve plots the object loss over the course of training. Object loss is a more general term that might encompass both box loss and classification loss, The interpretation of this graph would be similar to the previous two graphs. A decreasing curve signifies the model is learning to better predict both the bounding boxes and the classifications (fire vs background) of fire objects in the images.

4. The downward trend and flattening of the curve at low loss values indicate that the model has successfully from the training data and can make good predictions on new unseen images of fire.

6.4 Discussion

The culmination of our research and testing efforts underscores the transformative potential of our landfill fire detection and suppression system. By amalgamating technologies such as infrared camera monitoring and autonomous drones, we've devised a pioneering solution that redefines landfill fire management.Our system's ability to swiftly detect temperature fluctuations, even at their nascent stages, promises to revolutionize response times. This proactive approach not only curtails the spread and severity of fires but also minimizes environmental damage by limiting harmful emissions. Furthermore, the integration of autonomous drones for fire suppression tasks ensures rapid intervention, even in inaccessible areas, thereby enhancing overall efficacy.

Through rigorous testing and validation, we've demonstrated the robustness and reliability of our system. From the meticulous evaluation of our fire detection model to the seamless communication infrastructure between servers and clients, each component has been meticulously scrutinized to ensure optimal performance.

Quantitatively, our system exhibits commendable metrics, including a high F1 score, indicating a balance of precision and recall in fire detection. Additionally, metrics such as mAP and recall underscore the model's proficiency in accurately identifying fires and localizing them within imagery. The downward trend and stabilization of loss metrics further affirm the model's convergence and effectiveness in predicting fire occurrences.

In conclusion, our landfill fire detection and suppression system signify a paradigm shift in waste management practices. Not only does it improve response times and mitigate environmental impact, but it also enhances safety for landfill operations. As we move forward, the deployment of this innovative solution promises to safeguard communities against the devastating effects of landfill fires, ensuring a safer and more sustainable future.

Chapter 7

Conclusions and Future Scope

In conclusion, the utilization of a two-drone system for fire detection and suppression presents a technologically advanced and efficient approach to tackling wildfires. The integration of surveillance and suppression drones enables early detection of potential fires, rapid response, and effective containment measures. This proactive system not only enhances the safety of targeted areas but also optimizes resource allocation and response times, thereby minimizing the potential damage caused by wildfires.

As for the future scope of this method, several avenues for improvement and expansion can be explored. Firstly, the incorporation of artificial intelligence algorithms for enhanced fire detection capabilities could further refine the accuracy and reliability of the surveillance drone. Additionally, advancements in materials and technologies for the suppression drone, such as more sophisticated fire suppression mechanisms or increased payload capacity, could contribute to more effective firefighting efforts.

Moreover, the integration of real-time communication systems between the drones and ground-based firefighting teams can streamline coordination and provide valuable data for strategic decision-making. Research into the development of autonomous navigation and obstacle avoidance systems for the drones could further enhance their operational capabilities in challenging environments.

In summary, the future scope lies in continuous innovation, leveraging emerging technologies, and refining the existing system to create a robust and adaptable solution for wildfire management. The ongoing collaboration between researchers, technologists, and firefighting agencies will be crucial in unlocking the full potential of drone-based firefighting systems for the benefit of community safety and environmental preservation.

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Appendix A: Presentation

Project Presentation

SkySentry : Unmanned Aerial Systems for Fire Detection and Suppression in Open Environments

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Rajagiri School Of Engineering and Technology
Dept. of CSE

May 2, 2024

Project Guide:
Ms. Sangeetha Jamal
Asst. Professor, Dept. of CSE

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1. Problem Definition
2. Project Objective
3. Gantt Chart
4. 30% Output & Screenshots
5. Work Progress for 60% Evaluation
6. Results
7. Future Scope
8. Work Breakdown and Responsibilities
9. Conclusion
10. References

Problem Definition

Large open area fires often go undetected, posing significant environmental and human health risks due to impractical manual monitoring.

Project Objective

The primary objective of this project is to develop and implement an automated landfill fire monitoring and suppression system that uses drone technology and intelligent automation to detect, respond to, and suppress potential fire incidents in landfills, with a focus on improving environmental safety and preventing fire-related damage.

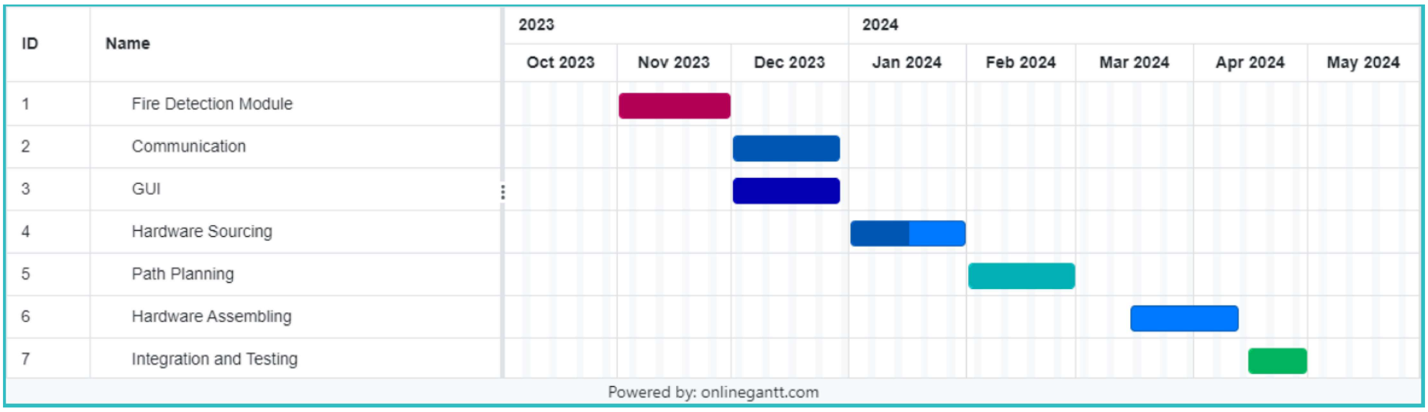
Novelty of Idea

- Integration of specialized fully autonomous UAVs for fire detection and suppression.
- Utilizes advanced sensors and autonomous capabilities.
- Represents a significant advancement in open environment fire management.
- Offers proactive and efficient approach to combating fires.

Scope of Implementation

- Design and construction of two distinct UAV platforms.
- Integration of advanced sensors and autonomous navigation systems.
- Rigorous testing and validation under various conditions.
- Considerations for scalability, regulatory compliance, safety, and environmental impact.
- Multidisciplinary effort involving robotics, aerospace engineering, wildfire science, and regulatory compliance.

Gantt Chart



- The development process followed is the agile model.

30% Output & Screenshots

The progress in modules :

- **Fire Detection Module**
  Live video snippet uploaded.
  The video snippet was divided into frames.
  A custom YoLov5 model was used to detect the presence of fire in these frames.
- **Communication Module**
  Established a Server Client connection between two devices and sent a video stream from server to client when a fire is detected.
- **GUI**
  Implemented a GUI to show location of fire on a map once location coordinates was entered into a CSV file.

30% Output

Figure: Fire detection model on a video sample

30% Output

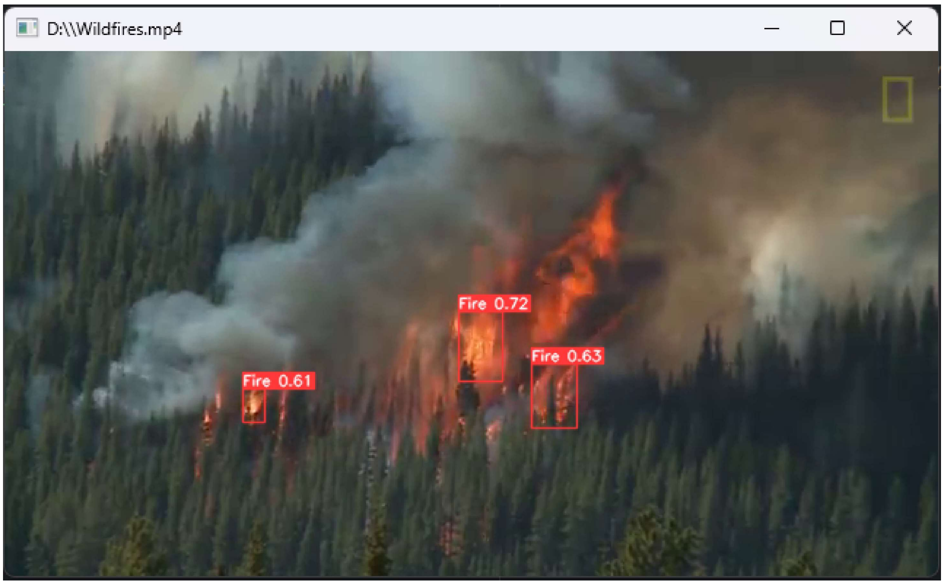


Figure: Fire detection model on a video sample

30% Output

Figure: GUI showing location on a map

30% Output

Figure: Server Sending Video Frames

Figure: Client Receiving Video Frames

Work Progress for 60% Evaluation

- Simulation of drone flight:
  - The target altitude and airspeed are taken as input.
  - This information is passed to the dronekit-sitl virtual copter.
  - The flight of the drone and other telemetry information can be viewed using Mission Planner.
- Hardware with drone frame, motors, and battery procured

Results

Figure: scripting mission by establishing waypoints

Results

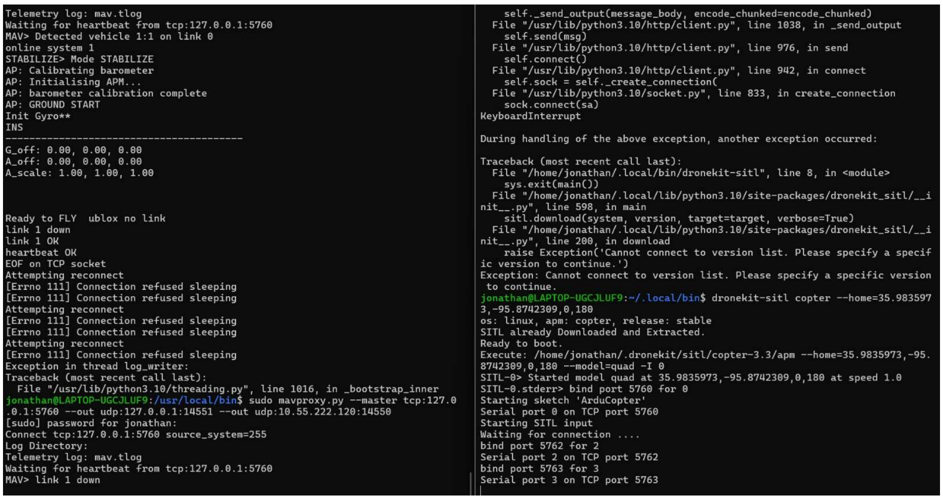


Figure: terminal controlling the drone communication

Future Scope

The project lays the foundation for several potential avenues of future development and expansion:

- Enhanced Sensor Integration
- Advanced Autonomous Capabilities
- Scalability and Fleet Deployment
- Community Engagement and Partnerships

Work Breakdown and Responsibilities

- Krishnadas Balachandran - Fire detection, Collision avoidance, Communication
- Jonathan Antony - Communication, Autonomous navigation
- Justin Joshy - Hardware, Obstacle detection, Fire Detection
- Joel Joseph Justin - Drone Procurement, GUI Software

Conclusion

The proposed landfill fire detection and suppression system, which integrates infrared camera monitoring and autonomous drones, represents a significant advancement in landfill fire management. This system offers improved response times, reduced environmental impact, and enhanced safety for landfill operations. Implementing this solution can help mitigate the potentially devastating effects of landfill fires.

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Appendix B: Vision, Mission, Programme Outcomes and Course Outcomes

Vision, Mission, Programme Outcomes and Course Outcomes

Institute Vision

To evolve into a premier technological institution, moulding eminent professionals with creative minds, innovative ideas and sound practical skill, and to shape a future where technology works for the enrichment of mankind.

Institute Mission

To impart state-of-the-art knowledge to individuals in various technological disciplines and to inculcate in them a high degree of social consciousness and human values, thereby enabling them to face the challenges of life with courage and conviction.

Department Vision

To become a centre of excellence in Computer Science and Engineering, moulding professionals catering to the research and professional needs of national and international organizations.

Department Mission

To inspire and nurture students, with up-to-date knowledge in Computer Science and Engineering, ethics, team spirit, leadership abilities, innovation and creativity to come out with solutions meeting societal needs.

Programme Outcomes (PO)

Engineering Graduates will be able to:

1. Engineering Knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

2. Problem analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

4. Conduct investigations of complex problems: Use research-based knowledge including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

5. Modern Tool Usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

6. The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal, and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

7. Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

9. Individual and Team work: Function effectively as an individual, and as a member or leader in teams, and in multidisciplinary settings.

10. Communication: Communicate effectively with the engineering community and with society at large. Be able to comprehend and write effective reports documentation. Make effective presentations, and give and receive clear instructions.

11. Project management and finance: Demonstrate knowledge and understanding of engineering and management principles and apply these to one's own work, as a member and leader in a team. Manage projects in multidisciplinary environments.

12. Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and lifelong learning in the broadest context of technological change.

Programme Specific Outcomes (PSO)

A graduate of the Computer Science and Engineering Program will demonstrate:

PSO1: Computer Science Specific Skills
The ability to identify, analyze and design solutions for complex engineering problems in multidisciplinary areas by understanding the core principles and concepts of computer science and thereby engage in national grand challenges.

PSO2: Programming and Software Development Skills
The ability to acquire programming efficiency by designing algorithms and applying standard practices in software project development to deliver quality software products meeting the demands of the industry.

PSO3: Professional Skills
The ability to apply the fundamentals of computer science in competitive research and to develop innovative products to meet the societal needs thereby evolving as an eminent researcher and entrepreneur.

Course Outcomes (CO)

Course Outcome 1: Model and solve real world problems by applying knowledge across domains (Cognitive knowledge level: Apply).

Course Outcome 2: Develop products, processes or technologies for sustainable and socially relevant applications (Cognitive knowledge level: Apply).

Course Outcome 3: Function effectively as an individual and as a leader in diverse teams and to comprehend and execute designated tasks (Cognitive knowledge level: Apply).

Course Outcome 4: Plan and execute tasks utilizing available resources within timelines, following ethical and professional norms (Cognitive knowledge level: Apply).

Course Outcome 5: Identify technology/research gaps and propose innovative/creative solutions (Cognitive knowledge level: Analyze).

Course Outcome 6: Organize and communicate technical and scientific findings effectively in written and oral forms (Cognitive knowledge level: Apply).

Appendix C: CO-PO-PSO Mapping

COURSE OUTCOMES:

After completion of the course the student will be able to

SL.NO	DESCRIPTION	Blooms' Taxonomy Level
CO1	Model and solve real world problems by applying knowledge across domains (Cognitive knowledge level:Apply).	Level 3: Apply
CO2	Develop products, processes or technologies for sustainable and socially relevant applications. (Cognitive knowledge level:Apply).	Level 3: Apply
CO3	Function effectively as an individual and as a leader in diverse teams and to comprehend and execute designated tasks. (Cognitive knowledge level:Apply).	Level 3: Apply
CO4	Plan and execute tasks utilizing available resources within timelines, following ethical and professional norms (Cognitive knowledge level: Apply).	Level 3: Apply
CO5	Identify technology/research gaps and propose innovative/creative solutions (Cognitive knowledge level:Analyze).	Level 4: Analyze
CO6	Organize and communicate technical and scientific findings effectively in written and oral forms (Cognitive knowledge level:Apply).	Level 3: Apply

CO-PO AND CO-PSO MAPPING

	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10	PO 11	PO 12	PSO 1	PSO 2	PSO 3
CO 1	2	2	2	1	2	2	2	1	1	1	1	2	3		
CO 2	2	2	2		1	3	3	1	1		1	1		2	
CO 3									3	2	2	1			3
CO 4					2			3	2	2	3	2			3
CO 5	2	3	3	1	2							1	3		
CO 6					2			2	2	3	1	1			3

3/2/1: high/medium/low

JUSTIFICATIONS FOR CO-PO MAPPING & CO-PSO MAPPING

MAPPING	LOW/MEDIUM/ HIGH	JUSTIFICATION
100003/ CS722U.1-PO1	M	Knowledge in the area of technology for project development using various tools results in better modeling.
100003/ CS722U.1-PO2	M	Knowledge acquired in the selected area of project development can be used to identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions.

100003/ CS722U.1-PO3	M	Can use the acquired knowledge in designing solutions to complex problems.
100003/ CS722U.1-PO4	M	Can use the acquired knowledge in designing solutions to complex problems.
100003/ CS722U.1-PO5	H	Students are able to interpret, improve and redefine technical aspects for design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
100003/ CS722U.1-PO6	M	Students are able to interpret, improve and redefine technical aspects by applying contextual knowledge to assess societal, health and consequential responsibilities relevant to professional engineering practices.
100003/ CS722U.1-PO7	M	Project development based on societal and environmental context solution identification is the need for sustainable development.
100003/ CS722U.1-PO8	L	Project development should be based on professional ethics and responsibilities.
100003/ CS722U.1-PO9	L	Project development using a systematic approach based on well defined principles will result in teamwork.
100003/ CS722U.1-PO10	M	Project brings technological changes in society.

100003/ CS722U.1-PO11	H	Acquiring knowledge for project development gathers skills in design, analysis, development and implementation of algorithms.
100003/ CS722U.1-PO12	H	Knowledge for project development contributes engineering skills in computing & information gatherings.
100003/ CS722U.2-PO1	H	Knowledge acquired for project development will also include systematic planning, developing, testing and implementation in computer science solutions in various domains.
100003/ CS722U.2-PO2	H	Project design and development using a systematic approach brings knowledge in mathematics and engineering fundamentals.
100003/ CS722U.2-PO3	H	Identifying, formulating and analyzing the project results in a systematic approach.
100003/ CS722U.2-PO5	H	Systematic approach is the tip for solving complex problems in various domains.
100003/ CS722U.2-PO6	H	Systematic approach in the technical and design aspects provide valid conclusions.
100003/ CS722U.2-PO7	H	Systematic approach in the technical and design aspects demonstrate the knowledge of sustainable development.

100003/ CS722U.2-PO8	M	Identification and justification of technical aspects of project development demonstrates the need for sustainable development.
100003/ CS722U.2-PO9	H	Apply professional ethics and responsibilities in engineering practice of development.
100003/ CS722U.2-PO11	H	Systematic approach also includes effective reporting and documentation which gives clear instructions.
100003/ CS722U.2-PO12	M	Project development using a systematic approach based on well defined principles will result in better teamwork.
100003/ CS722U.3-PO9	H	Project development as a team brings the ability to engage in independent and lifelong learning.
100003/ CS722U.3-PO10	H	Identification, formulation and justification in technical aspects will be based on acquiring skills in design and development of algorithms.
100003/ CS722U.3-PO11	H	Identification, formulation and justification in technical aspects provides the betterment of life in various domains.
100003/ CS722U.3-PO12	H	Students are able to interpret, improve and redefine technical aspects with mathematics, science and

		engineering fundamentals for the solutions of complex problems.
100003/ CS722U.4-PO5	H	Students are able to interpret, improve and redefine technical aspects with identification formulation and analysis of complex problems.
100003/ CS722U.4-PO8	H	Students are able to interpret, improve and redefine technical aspects to meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
100003/ CS722U.4-PO9	H	Students are able to interpret, improve and redefine technical aspects for design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
100003/ CS722U.4-PO10	H	Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools for better products.
100003/ CS722U.4-PO11	M	Students are able to interpret, improve and redefine technical aspects by applying contextual knowledge to assess societal, health and consequential responsibilities relevant to professional engineering practices.
100003/ CS722U.4-PO12	H	Students are able to interpret, improve and redefine technical aspects for demonstrating the knowledge of, and need for sustainable development.

100003/ CS722U.5-PO1	H	Students are able to interpret, improve and redefine technical aspects, apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
100003/ CS722U.5-PO2	M	Students are able to interpret, improve and redefine technical aspects, communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
100003/ CS722U.5-PO3	H	Students are able to interpret, improve and redefine technical aspects to demonstrate knowledge and understanding of the engineering and management principle in multidisciplinary environments.
100003/ CS722U.5-PO4	H	Students are able to interpret, improve and redefine technical aspects, recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.
100003/ CS722U.5-PO5	M	Students are able to interpret, improve and redefine technical aspects in acquiring skills to design, analyze and develop algorithms and implement those using high-level programming languages.
100003/ CS722U.5-PO12	M	Students are able to interpret, improve and redefine technical aspects and contribute their engineering skills

		in computing and information engineering domains like network design and administration, database design and knowledge engineering.
100003/ CS722U.6-PO5	M	Students are able to interpret, improve and redefine technical aspects and develop strong skills in systematic planning, developing, testing, implementing and providing IT solutions for different domains which helps in the betterment of life.
100003/ CS722U.6-PO8	H	Students will be able to associate with a team as an effective team player for the development of technical projects by applying the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
100003/ CS722U.6-PO9	H	Students will be able to associate with a team as an effective team player to identify, formulate, review research literature, and analyze complex engineering problems
100003/ CS722U.6-PO10	M	Students will be able to associate with a team as an effective team player for designing solutions to complex engineering problems and design system components.
100003/ CS722U.6-PO11	M	Students will be able to associate with a team as an effective team player, use research-based knowledge and research methods including design of experiments, analysis and interpretation of data.

100003/ CS722U.6-PO12	H	Students will be able to associate with a team as an effective team player, applying ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
100003/ CS722U.1-PSO1	H	Students are able to develop Computer Science Specific Skills by modelling and solving problems.
100003/ CS722U.2-PSO2	M	Developing product processes or technologies for sustainable and socially relevant applications can promote Programming and Software Development Skills.
100003/ CS722U.3-PSO3	H	Working in a team can result in the effective development of Professional Skills.
100003/ CS722U.4-PSO3	H	Planning and scheduling can result in the effective development of Professional Skills.
100003/ CS722U.5-PSO1	H	Students are able to develop Computer Science Specific Skills by creating innovative solutions to problems.
100003/ CS722U.6-PSO3	H	Organizing and communicating technical and scientific findings can help in the effective development of Professional Skills.