Fire Alert System

(Conceptual Design)

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Table of Contents

Abstract

Wildfires are a major danger to forests, wildlife, people, and the economy as they are getting worse because of climate change and human actions. This report describes a plan for an automatic fire alert system that uses drones to watch over large open forests in these areas. The drone can navigate through heat and smoke using sensor fusion and make autonomous decisions to fly out and map the forest area look for fires, report the exact location of the fire to the ground station, and also help in extinguishing it. This also explores the question of how to navigate the drone quickly and safely in an unpredictable environment, monitor huge forest areas in real-time and send information to firefighters on the ground so they can get help fast when a fire starts. A hybrid approach is considered as the solution for the problem of navigation which combines the three major visual-based navigation methods like Map-based navigation system, Obstacle detection and avoidance approaches and Path planning-based approaches. The navigation system can use both regular maps and obstacle avoidance to keep the drone safe it combines these methods so the drone can adjust its flight path based on what the sensors see in real-time making the whole fire alert system more reliable and efficient.

Introduction

Forest wildfires are a huge threat to ecological areas, plant and animal life, human safety, and the economy. Their frequency and intensity are increasing due to climate change and human activities. This begs the urgent need for new and improved solutions to detect wildfires early and respond quickly. This technical report discusses the conceptual design of an autonomous fire alert system that uses UAV drone technology to monitor large unstructured forest environments. The severity of the wildfires especially in regions like the Arizona forest where human negligence and dry environmental conditions lead to frequent outbreaks(Tedim et al., 2018), demands an effective solution. The report examines the navigation system's ability to navigate through the heat and smoke by using appropriate sensors and allows for quick manoeuvrability and reliability in an unstructured environment. It also examines the system's real-time monitoring capabilities across vast forest regions and discusses the communication methods for sharing information with ground response teams to provide extra help and speed up the response when a fire is detected. However effective navigation in forest environments poses a critical challenge due to obstacles like dense vegetation, uneven terrain, and mapping errors caused by landslides or weather-induced changes(Badrloo et al., 2022). Also, obstacles such as the growth of trees and plants can lead to altitude perception errors. Traditional map-dependent navigation systems can be used with local obstacle avoidance capabilities to protect the drone during the flight(Arafat, Alam and Moh, 2023), by including map-based navigation systems, obstacle detection using thermal sensors, LiDAR, computer vision and path planning can involve the best aspects of these approaches to dynamically plan and adjust flight paths based on real-time. This report aims for the overall functioning of the autonomous fire alert system and details navigation techniques for reliable and effective navigation in forests.

Alternatives / Technical solutions

Navigation systems are based on learning techniques that provide the ability to tread through uncertain and unstructured environments and observe by using different sensory inputs to ensure that the robot can be controlled and showcase better performance. However, issues such as uncertainties in the non-organized environment, incomplete perception, and inaccurate actuators make it harder to design an accurate navigation system. The design should be able to:

- Respond precisely and effectively to act on the immediate unexpected situation.
- Built on several complimenting input data in the process to avoid discrepancies in judgment.
- Reach the target based on the specific location of the object.

In UAVs or drones, the sense of their position and direction helps in deciding the optimal path to a target location and performing a specific task. To attain these goals, different navigation approaches are discussed. Some of the widely used navigation techniques in aerial robotics are the Global Navigation Satellite System, Inertial Navigation System, Barometric Altimeter, Visual Odometry, RF Beacons, LiDAR, and Magnetic Compass.(Yuan, Zhang and Liu, 2015)

These techniques are used as per the requirements of the designed system. For example, the Global Positioning System provides accurate positioning data using satellite signals for precise location determination and navigation. The Inertial Navigation System utilizes accelerometers and gyroscopes to measure changes in velocity and orientation, allowing UAVs to estimate their position and velocity without external references. It is useful in indoor or urban environments where GPS signals might become unreliable.

Barometric altimeters measure air pressure to determine altitude above sea level and are used in determining accurate altitude information for UAVs(Manoj and Valliyammai, 2023). Visual odometry counts on camera and image processing algorithms to track features in the environment and estimate the UAV's motion relative to its surroundings(Khan et al., 2022). Sensor fusion can aid this approach using tele-op data from multiple sensors like LiDAR sensors, cameras, and GPS data(Zhou, Durrani and Guo, 2020). It can aid in localization and navigation in GPS-denied environments or during close-range operations, such as indoor navigation or obstacle avoidance. Producing consistent results and managing the navigational tasks requires high accuracy.

For this activity, The Visual-based UAV approach is the most appropriate one as it empowers the drone to navigate in an unstructured environment by sensing the potential obstacle within the way of getting to a point, which cannot be achieved by using other methods. Figure 1 shows a detailed categorization of vision-based UAV navigation systems.(Arafat, Alam and Moh, 2023)

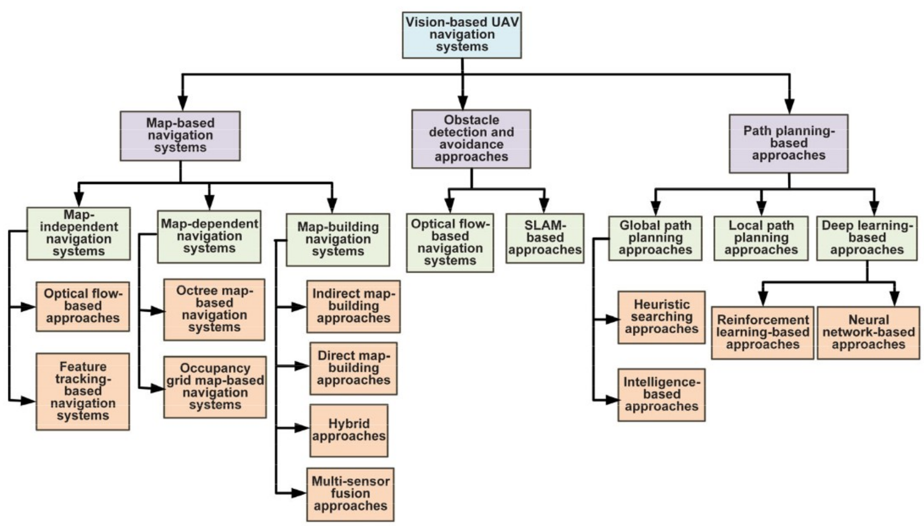

Figure 1. Categorization of vision-based UAV navigation systems(Arafat, Alam and Moh, 2023)

Within the Visual-based approach, there are three potential approaches:-

1. Map-based navigation system
2. Obstacle detection and avoidance approaches
3. Path planning-based approaches

Map-based navigation system

Drones navigate and plan movements based on predefined data from maps and the spatial layout of the environment(Badrloo et al., 2022). These systems can be categorized into three types:

1. Map-dependent: UAVs navigate using pre-existing maps, which can range from 3D models of the entire environment to diagrams showing connections between objects.
2. Map-building-based: UAVs create maps of the environment as they navigate, combining data from sensors and observations.
3. Map-independent navigation: Using techniques like optical flow, in which the drone estimates motion by analyzing pixel movements between frames.(Badrloo et al., 2022)

Obstacle detection and avoidance navigation systems

This can be described as identifying surrounding obstacles and calculating the distance to manoeuvre through obstacles and reduce the risk of collisions. There are two main methods:

1. Optical flow-based methods that examine images captured by a single camera to detect obstacles and estimate depth using techniques like the Lucas-Kanade method, and bionic insect vision algorithms which detect the obstacles by comparing successive images and determine the distance change. (Yuan, Zhang and Liu, 2015)

2. Using SLAM (Simultaneous Localization and Mapping) to generate precise maps of the environment while localizing the drone's position using libraries like ORB-SLAM which computes the camera trajectory and a sparse 3D reconstruction, they can work in indoor environments and low light conditions where using GPS might be an unreliable approach.(Zhou, Durrani and Guo, 2020)

Path Planning Approach

This approach tries to find the most efficient route between starting and ending points, considering factors like shortest distance, flight time, and obstacle avoidance. There are two major types of approaches:

1. Global path planning which uses the static map to create an initial path by using heuristic search algorithms like A-star and more complex approaches like genetic algorithms and simulated annealing.(Zhou, Durrani and Guo, 2020)

2. Local path planning which employs real-time sensor data to continuously adjust the path and avoid obstacles in unconstrained environments. It can achieve this by using several techniques like spatial search methods, artificial potential field techniques, fuzzy logic techniques and neural networks.(Zhou, Durrani and Guo, 2020)

In path planning, global planning provides the initial route and local planning refines it in flight in real time using sensor data. Integration with path planning algorithms like RRT (Rapidly Exploring Random Tree) is appropriate for generating collision-free paths based on obstacle information.(Arafat, Alam and Moh, 2023)

Feasibility and Evaluation

The feasibility and evaluation describe the likelihood of a system to best fit the application as per the considered factors like sensory inputs, functions, limitations, advantages, and environment structure and to gauge the appropriate method required for our application.

There are specific sets of capabilities required by the navigation system to ensure the feasibility of the drone to work on a fire alert system:

1. Precise localization should be achieved and environment mapping.
2. Adaptive path planning for path correction in unforeseen situations and re-planning the path.
3. Good perception and analysis of the environment to overcome obstacles.
4. Failsafe design in hardware failure situations and showcase eventuality measures.
5. Communication and coordination with the central network and ground stations to send real-time location of the drone.
6. Regulatory compliance as per the government measures of safety and reliability.

The table below evaluates the methods.

Method	description	functions	Sensory inputs	Advantages	Disadvantages
Map-based navigation system	use of predetermined maps and spatial information to navigate	Building maps and updating them as per the environment change	Visual sensors like a camera; Ranging sensors like LiDAR; Inertial sensors (IMU)	high situational awareness;	Relies on pre-existing maps
Obstacle detection and avoidance navigation systems	Identifies obstacles and manoeuvres around them and reduces the risk of collisions.	Enables indirect routing and re-aligning to the original path	Visual sensors like a camera; Ranging sensors like LiDAR; Inertial sensors (IMU)	Safe navigation by avoiding obstacles and collisions	sensitivity to light shifts, camera shaking, and outdoor noise
Path Planning Approach	Find the most efficient route between starting and ending points, considering factors like shortest distance, flight time, and obstacle avoidance	Global path planning finds initial route; Local path planning continuously adjust the path	Global path planning has Static map data; Local path planning has real-time camera and LiDAR sensor data	Global path planning does efficient route planning in the initial phase; Local path planning dynamically adjusts the path	Global path planning does not account for moving objects; Local path planning requires accurate sensor data processing.

The table evaluates the methods and sheds light on the fact that every approach has a disadvantage but a collective system working on all three approaches can outperform any single approach in this application.

Decision and conclusions

A hybrid approach combining map-based navigation obstacle detection and path planning offers a strong resolution for this task.

Map-based navigation can be used to pre-determine the map of the forest similar to a roadmap. This map provides a general understanding of the terrain including landmarks potential paths and open areas it acts as a starting point for the drone flight allowing it to plan its overall trajectory within the forest.

Obstacle detection and avoidance help to make manoeuvrability and path correction easy in an unstructured environment with trees, rocks, and uneven terrain. LiDAR, thermal cameras, and computer vision examine the surroundings for potential hazards. When an obstacle is encountered, the sensors detect and trigger an immediate avoidance manoeuvre related to the drone's original trajectory, ensuring the drone's safety and preventing collisions.

Path planning constantly adjusts the flight path based on both the pre-loaded map and the real-time sensor data from obstacle avoidance and recalculates its route to deviate from the initial map path to avoid a newly detected obstacle.

This approach diminishes major disadvantages of any single approach and enhances the merits of the overall navigation system.

UAVs have minimum to no negative effects on variation in the natural habitat of land animals but bother aerial animals like birds and insects.(Ivanova, Prosekov and Kaledin, 2022)

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