Fire Front Detection and Tracking for Autonomous sUAS in STEReO

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The Scalable Traffic Management Emergency Response Operations (STEReO) project aims to incorporate unmanned aerial systems (UAS) into wildfire incident response to safely quicken response times, improve operator awareness, and scale-up aircraft operations. Autonomous UAS can be used to relieve human operators of dull, dirty, and dangerous tasks such as checking for re-ignitions and geo-locating fires. To geo-locate fires, the UAS must be able to detect whether a fire is present and also have the necessary information to stamp a location. Furthermore, the UAS should be able to track the fire front to determine the extent of the fire. This study presents a fire front detection and tracking methodology for an autonomous small UAS (sUAS). The methodology is evaluated in simulation.

I. Introduction

Wildfires demand stringent, standardized response from both manned aircraft and ground operations. During a wildfire scenario, a Fire Traffic Area (FTA) is erected 5 nautical miles radially around the fire and extends at least 2500 feet above ground level (AGL). This is separate from the FAA-established Temporary Flight Restriction (TFR) that legally restricts aircraft from entering the airspace. The FTA is a communication tool that establishes protocol within firefighting agencies. If a TFR is in place over a wildfire incident, the FTA rules apply to the TFR. The Interagency Aerial Supervision Guide[1] details standardized procedures that allow different agencies who are responding to wildfire scenarios to collaborate without prior rehearsal.

For decades, manned aircraft has been the primary platform for fire detection due to their maneuverability, speedy deployment, and mission flexibility.[2] However, visual detection by personnel on the ground remains a prevalent task, albeit a dull, dirty, and dangerous one. It is often more time and cost efficient for an observer on the ground to make their way to a location to check a fire spread than it is for a manned aircraft to be deployed. Unmanned aerial vehicles (UAV) can be employed to bridge the gap between the duties of manned aircraft and ground personnel. Due to their size, UAVs are more mobile, lower cost, and even quicker to deploy than manned aircraft while being much safer than sending out a human to do the task. As such, much research has been conducted on leveraging UAVs with onboard sensors for fire monitoring and detection.[3] However, due to the regulations around aircraft in an FTA, most research has been limited to simulations or flight tests observing controlled burns.

At the time of this study, there are no standard procedures for incorporating unmanned aerial systems (UAS) into wildfire incidents under an FTA. PMS 515[4] outlines the minimum standards for implementing UAS in FTA, but does not go into detail on mission and platform types. To safely integrate UAS into wildfire incidents with manned aircraft, the Scalable Traffic Management Emergency Response Operations (STEReO) project seeks to leverage the UAS Traffic Management (UTM) infrastructure[5] designed by NASA to safely allocate airspace of UAS in urban environments. STEReO's main goals are to incorporate UAS in wildfire incidents in ways that improve disaster response times and operator awareness, enable large-scale aircraft operations, and demonstrate safety and resiliency.[6]

This study is also part of the Safe Autonomous Flight Environment (SAFE50)[7] project that focuses on incorporating autonomy into UAS flying in urban environments below 50 ft. Many of the difficulties in urban

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flight carry over to to wildfire incidents, including environmental challenges, atmospheric uncertainty, failures and contingencies, shared airspace with other manned and unmanned aircraft, and presence of static and dynamic ground objects. To address these challenges in an urban setting, SAFE50 has researched LIDAR simultaneous localization and mapping (SLAM),[8] onboard decision-making,[9] local path planning,[10] vehicle-to-vehicle communication for cooperative collision avoidance,[11] dynamic ground risk mitigation,[12] and global path planning.[13] Figure 1 shows some of the hazards a wildfire incident and fire fighting response may pose on a UAS. The previous work done by SAFE50 can be applied to these hazards, but do not cover actual mission objectives. One powerful UAS application to wildfire incidents is in fire information gathering. This includes monitoring, detecting, tracking, and mapping fires.

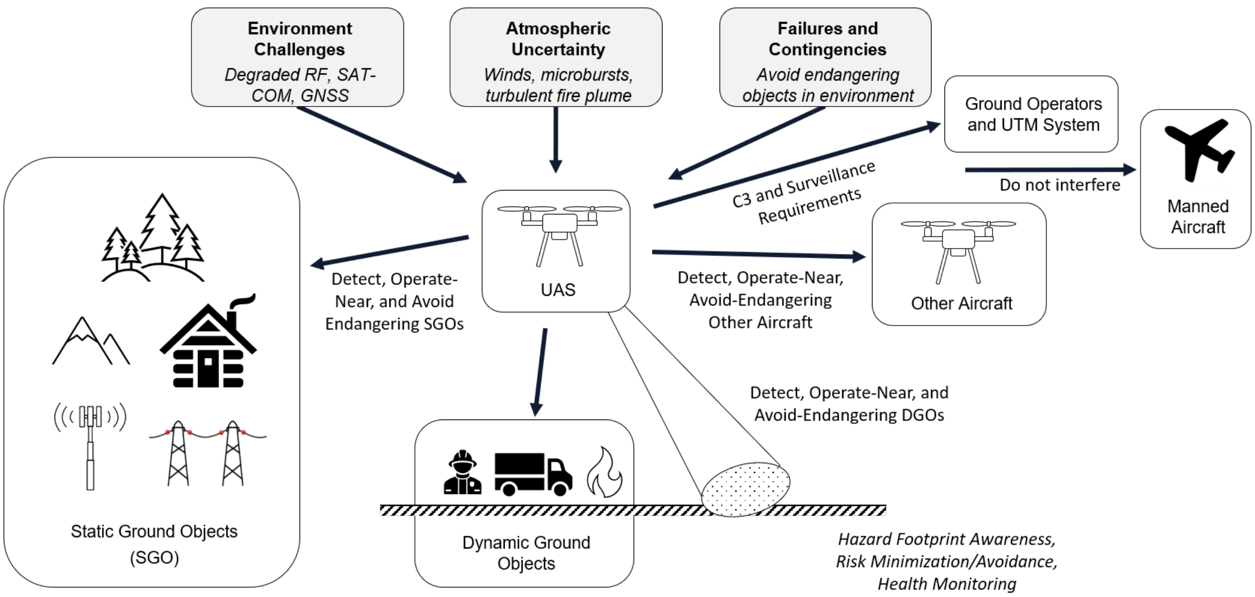

Figure 1: Potential hazards to UAS flying in wildfire incidents.

A. Contribution

The focus of this study is the detection and tracking of fire fronts by an autonomous small UAS (sUAS), where a "small" UAS is defined as under 50 lbs*. The sUAS utilizes a thermal infrared (TIR) and visible light dual camera to both detect the fire and reference its location relative to the aircraft position. The sUAS continues to gather fire position information to track the boundary of the fire front. In addition to the sensors being onboard the aircraft, all of the processing is done online. This reduces the communication requirements between the aircraft and ground station and also enables the aircraft to make decisions on-the-fly. The sUAS studied are multirotors rather than the commonly used fixed-wings. While having shorter endurance and lower payload capacity than fixed-wings, multirotors are more maneuverable, can hover in place to loiter, and do not require a runway to take-off and land. As part of the STEReO project, the sUAS leverages the UTM infrastructure by connecting to a UAS Service Supplier (USS) that approves UAS operations. Fires are detected and tracked within the airspace allocated in this approved operation.

II. Methodology

A. Fire Detection

Yuan et al.[3] conducted a survey on vision-based techniques for UAV fire monitoring, detection, and fighting. Most of the platforms surveyed are fixed-wing aircraft with either online or offline methodologies. Vision-based fire detection uses sensors in IR bands, visual bands, or a combination of the two. The two main targets for detection are flame and smoke. Color vision sensors are mostly used for segmenting the fire areas

*https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId = 22615 by detecting the flame itself, but can also be used to track smoke and geometry. IR sensors detect the actual fire by measuring the radiated heat. Thus, IR sensors can "see" through smoke and can function during nighttime. Important geometrical features for geolocating fires include fire front location, fire site width and perimeter, flame length and height, inclination angle, coordinates of burnt areas, and location of hotspots.

The infrared spectrum consists of more discrete wavelength bands: near-infrared (NIR), short-wavelength infrared (SWIR), medium-wavelength infrared (MWIR), and long-wavelength infrared (LWIR), commonly called thermal infrared (TIR). MWIR and TIR are the preferred bands for fire detection due to the emissivity characteristics of fire at these wavelengths.[2] Multispectral sensors can also be employed to simultaneously obtain the advantages of both MWIR and TIR bands. NASA's Autonomous Modular Scanner (AMS)-Wildfire sensor consisted of a multispectral camera that used MWIR bands for fire detection in combination with TIR bands to reduce false alarms.[14]

The fire detection sensor used in this study is a FLIR Duo R. The Duo R is a thermal infrared (7.5–13.5 μm) and visible light dual camera with a small form factor that is easily mounted on UAVs. More research will be done on how to effectively utilize the TIR and visible light sensors on the Duo R (i.e. detection criteria for denoting burning pixel, relevant flame characteristics for building a fire map, camera pose relative to the aircraft). A UAS utilizing a multispectral camera capable of operating in the MWIR band may be added to the methodology.

B. UAS Fire Front Tracking

While detecting a fire is a matter of positioning the UAS so the fire is in view, the question remains on how to keep the fire in view or even find it. A sensor-based area coverage scheme can be used to sweep an entire designated area in search of fires.[15] After finding the general shape, size, and location of the fire, the fire front can be tracked as a boundary perimeter using a team of UAVs.[16–20] The work conducted by Casbeer et al[16] is of particular interest as their tracking scheme creates waypoints to guide the aircraft along the boundary. Section III goes over how our aircraft utilize waypoints for autonomous flying.

III. System Architecture

NASA's in-house Reflection Architecture[21] serves as the control framework for all of the autonomy capabilities on the UAS. Figure 2 shows the SAFE50 vehicle system architecture used by Reflection. Sensor hardware and external communications are input into the autonomy architecture to the Sensor Processing Modules. Waypoint flight plans are created using information on the environment, vehicle state, and mission goals and passed onto the Low-Level Flight Control System (FCS). Separating the high-level and low-level FCS allows much of the autonomy structure to be platform agnostic.

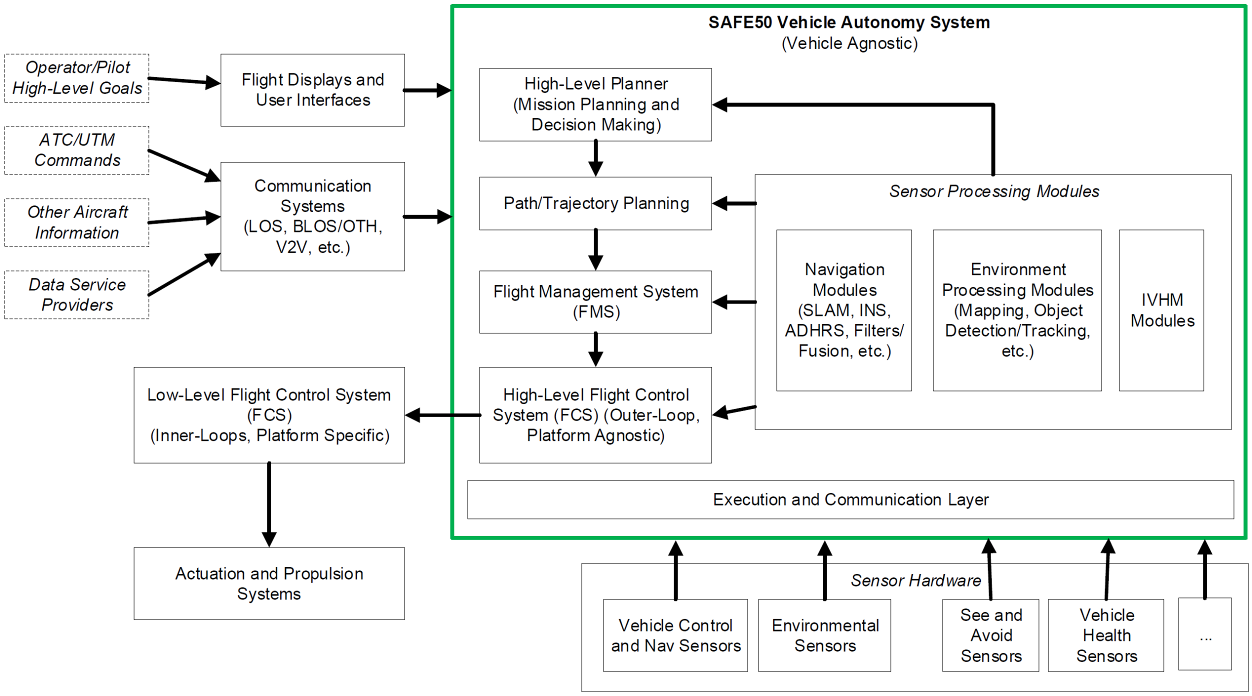

Figure 2: SAFE50 vehicle system architecture.

IV. Simulation

In addition to acting as the control framework, Reflection also serves as a simulation environment for testing software flight-readiness. Multiple UAS and sensors can be simulated in varying terrain with fire to create as close to a real-world scenario as possible. The detection and tracking algorithms will be tested in Reflection using a dynamic fire model.

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