Surefire UAV: A CPS Testbed

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***Abstract*—Urban firefighting faces significant challenges in acquiring temperature data within complex building structures during rapid urbanization. The Surefire UAV testbed was developed to address this challenge. The testbed leverages an unmanned aerial vehicle (UAV) equipped with a spherical sensor, capable of being deployed at designated target points to collect temperature data. This testbed is a typical Cyber-Physical System (CPS) testbed, integrating both the cyber components (flight control software and sensor deployment software) and physical components (UAV hardware, sensors, motors, etc.).**

***Index Terms*—Surefire, UAV, Cyber-Physical System, Sensor, Indoor Navigation**

I. Introduction

With the rapid acceleration of urbanization, urban firefighting has emerged as a critical and widely discussed topic. The increasing density of urban building structures presents unprecedented challenges for fire prevention and emergency response. In high-rise buildings, underground spaces, and other confined environments, traditional firefighting methods often struggle to provide timely access to crucial fire-related information. Consequently, leveraging advanced technologies to enhance fire monitoring and rescue capabilities has become a central focus in urban firefighting. To address these pressing challenges, the Surefire UAV testbed was developed as a solution. The core objective of the testbed is to enable UAVs to fly to predefined target locations inside urban buildings and deploy spherical temperature sensors, which can then provide critical temperature data. This data supports downstream analysis systems that utilize room layouts and AI models to predict fire trends (As shown in Fig 1).

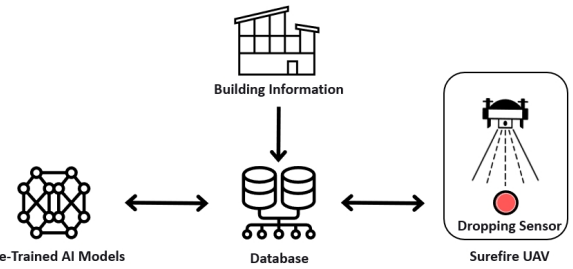


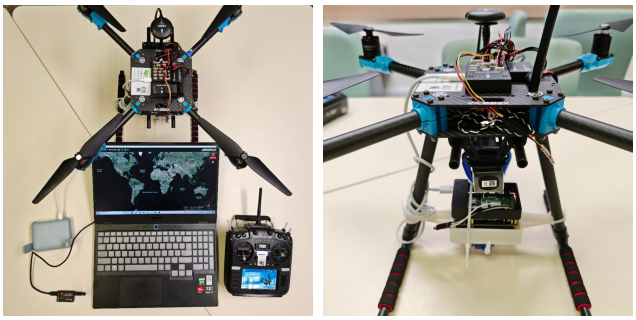
Fig. 1: The Surefire UAV Testbed (on the right side of the figure) and Other AI Fire Prediction Components

While the downstream fire analysis is beyond the scope of this work, the testbed focuses on developing the UAV and addressing the fundamental challenge of indoor sensor delivery. The Surefire UAV testbed is unique in its integration of cyber and physical components to address real-world challenges in smart firefighting. The cyber domain encompasses the flight control software and sensor deployment system, while the physical domain involves UAV hardware, sensors, and actuators. Its design serves as a platform for testing and validating theories in Cyber-Physical Systems (CPS) research.

II. Key Research Challenges

To ensure that the Surefire UAV testbed meets the demands of urban smart firefighting (there might be indoor environments), its design was guided by several key objectives. These objectives address the unique challenges posed by indoor environments and the need for precise sensor deployment. The main goals include:

- **CH1** Indoor Operation: Since the testbed is intended for use in indoor environments, it must be able to operate without GPS.
- **CH2** Remote Control: The UAV should be able to operate remotely to ensure precise timing and execution of the sensor deployment process.
- **CH3** Modularity and Scalability: The testbed architecture should be modular to facilitate future upgrades, such as the addition of new sensors or improved deployment mechanisms.



(a) Surefire UAV and Remote Controller (b) Sensor Deployment Components

Fig. 2: Surefire UAV Testbed

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III. Solution

To address the key research questions (RQ1–RQ3), the Surefire UAV testbed (Fig. 2) integrates the following technical solutions:

A. CH1: Indoor Operation without GPS

The testbed leverages the Ardupilot open-source flight control ecosystem [1] with a Pixhawk flight controller [2] and a TX16s remote controller [3]. This system enables a human pilot to operate the UAV in GPS-denied indoor environments through the remote controller (Fig. 2a).

B. CH2: Remote Control for Sensor Deployment

The Raspberry Pi 4 Model B [4] acts as the deployment command center: Upon receiving remote instructions, it executes the Python scripts that directly trigger the SG90 servo motor to deploy the sensor ball (Fig. 2b).

C. CH3: Modular and Scalable Architecture

The testbed adopts the Holybro UAV framework for hardware modularity, allowing rapid integration of new sensors or mechanisms. The Ardupilot ecosystem's open-source nature supports software scalability, facilitating future upgrades.

IV. Future Work

Currently, the Surefire UAV still requires a human pilot for flight control and sensor deployment. We are trying to integrate a depth camera to enable the UAV to scan its surrounding environment and generate a cloud point. By comparing this cloud point against a pre-recorded cloud point database of the building, the UAV can localize its position in the building. Upon reaching the target location, it will autonomously deploy the sensor ball.

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