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Autonomous Wildfire Tracking Systems Based on UAV and Perspectives of Wildfire Digital Twin

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Abstract

Digital twin, a new concept, which comes from the manufacturing industries, is introduced to different aspects of life. The ever-burgeoning development of digital twin systems lays the path for a new approach to wildfire monitoring and prevention. A real wildfire digital shadow reflects the fire development, providing a promising platform for firefighting decisions. However, currently, static terrain information cannot be integrated with dynamic wildfire locations, which is a great hindrance to the utilization of digital twin systems. The flame trend fails to be mapped in the digital shadow. The key to solving this issue is to ensure real-time data transfer. Thus, UAVs equipped with vision systems could be leveraged to maintain surveillance, transferring the real-time information to the digital twin systems. Initially, the study reviews the UAVs in wildfires. Specifically, the history of UAV tracking is introduced. Furthermore, the autonomous wildfire tracking system is proposed to assist in locating the fire front. A YOLO-based algorithm is utilized to detect the fire front. The UAVs use an orthographic view to locate the wildfire, controlling and maintaining the gesture with a perspective lock on the flame front. Then, UAVs track and follow the flame front without human intervention. In addition, the combination of UAV location information based on GPS and camera view information depicts the wildfire in the digital twin systems. This study aims to act as a pre-processing step for wildfire digital twin data transfer. It will provide a basis for the precise wildfire portrait in the virtual systems.

1. Introduction

1.1. UAVs in wildfire

The usage of unmanned aerial system (UAS) is not really a new concept, particularly in military uses throughout human civilization. An interesting early use of unmanned aerial technologies was the use of hot air balloons during the US Civil War or the installation of cameras in Kites during the Spanish-American War (Manzello, 2020). Yet, there are also historical accounts that pre-date these events by hundreds of years that have used the concept of unnamed aerial technologies for various purposes.

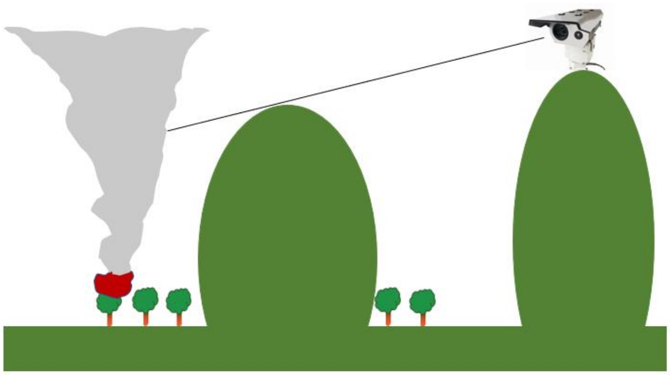

Figure 1- Restrictions of watch towers and fixed cameras installed on mountaintops

In wildland fire detection, monitoring and fighting, a view from higher elevations is desired to gain overall and unique fire information. Compared to a fixed camera network installed on mountain tops and fire watchtowers

(Fig. 1), the airborne monitoring system is more cost-effective and is not limited by the location of the pre-installed infrastructure. Airborne systems usually include high-altitude manned or unmanned aircraft (Allison et al., 2016; Colomina & Molina, 2014) and high-altitude long-duration balloons (Rand, 1994; REGO et al., 2010). As expected, the overall cost of unnamed aircraft and balloons is much lower compared to the manned system. Another important aspect is the risk of having people onboard aircraft during a mission. By using unmanned aircraft, it could avoid putting a crew at risk. Aviation accidents account for 18% of wildland fire fighting fatalities between 2007-2016 (National Wildfire Coordinating Group, 2017). UAVs are undoubtedly one of the most promising technology to ensure the safety of firefighters in wildfires. UAVs can shorten the time of firefighting response and render rescue activities safer, fast er, and more efficient (Khan et al., 2018). It has the ability to access hard-to-reach areas and help gather important data (Reich, 2016). Besides, they can replace the role of helicopters, which may be disturbed by smoke, increasing the risk of pilots in wildfires. The ability to require unmanned control and avoid unnecessary obstacles makes UAVs unique in firefighting. Their safety is not a priority so UAVs could take on more dangerous tasks. The current study about UAV usage in a wildfire is solely about monitoring and putting out fires. Burchan Aydin (Aydin et al., 2019) and his team were entrusted by the fire department of Texas to come up with a fire-distinguishing ball technology and then applied them with UAVs in wildfire fighting. This technology was also utilized to detect and monitor wildfires to reduce false alarms, increasing the efficiency of firefighters (Sudhakar et al., 2020). Since 2021, a platform has been already made use of to manage a number of UAVs in order to spread the liquid on wildland fires (Ausonio et al., 2021). Nowadays, a lot of teams have been focusing on the frameworks of UAV swarms because a single UAV is not enough for a big fire or wildfire so that more UAVs will be applied in the near future (Ausonio et al., 2021; Innocente & Grasso, 2019; Madridano et al., 2021; Roldán-Gómez et al., 2021).

1.2. Digital twin and UAVs

The concept of the digital twin comes from the manufacture industry, and it refers to presenting the real world with virtual methods (Boschert & Rosen, 2016)(Liu et al., 2021), introduced to other industries. Generally, the 3-Dimensional model with real-time data updates is considered as the digital twin/digital shadow, realizing the goal of data assimilation.

The ever-burgeoning development of digital twin systems lays the path for a new approach to wildfire monitoring and prevention. A real wildfire digital shadow reflects the fire development, providing a promising platform for firefighting decisions. However, currently, static terrain information cannot be integrated with dynamic wildfire locations, which is a great hindrance to the utilization of digital twin systems. The digital twin for wildfire is still a terrain model with no updated information. Even when the DJI company launched its newest product in March 2022, Flighthub 2, it simply integrated terrain models with real-time camera information (Fig. 2).

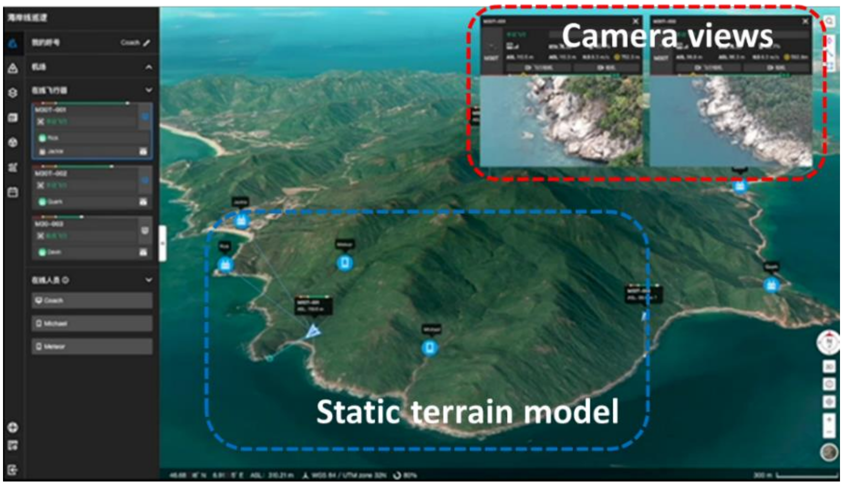

Figure 2- Terrain models integrated with camera views by DJI Company (from DJI FlightHub Website)

The wildfire head fails to be mapped in the digital shadow. The wildfire portrait in the digital twin systems is always a huge difficulty waiting to be solved. The issue lies in the failure of real-time wildfire data transfer. If the fire development trend could be recorded in time. It is possible to depict the wildfire in the digital twin systems. Gladly, UAVs equipped with vision systems could be leveraged to maintain surveillance, transferring the real-time information to the digital twin systems. However, with the increasing spread of wildfires, it is extremely hard for UAVs to update the geography information of wildfires. Thus, an autonomous wildfire tracking system based on UAVs is proposed to assist in locating the fire front. Since fuels, wind, and other factors resulted in the disordered spreading of wildfire, UAV swarms are utilized to collect information, synchronizing the fire front in the digital twins (Fig. 3).

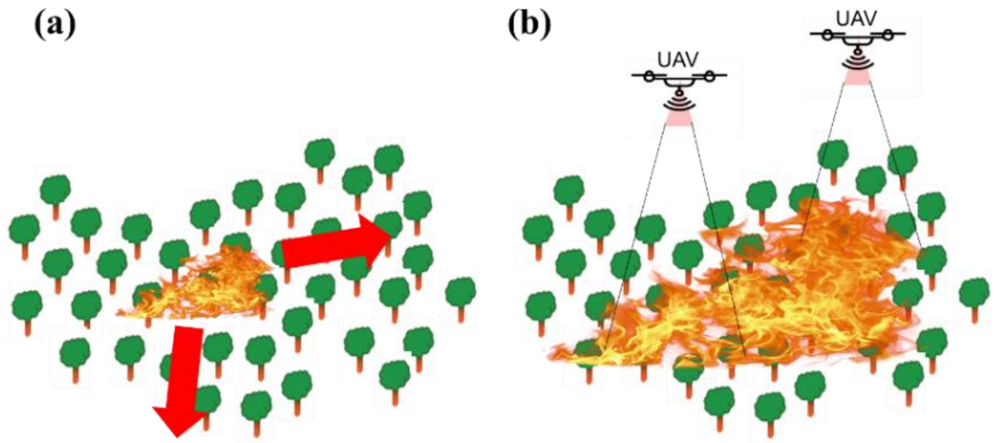

Figure 3- (a) Wildfire spreads following the wind, and (b) UAV follows wildfires in the main directions

The study aims to act as a pre-processing step for wildfire digital twin data transfer. It will provide a basis for the precise wildfire portrait in the virtual systems.

2. Methodology and framework

Object tracking in vision-assisted UAV systems requires three major steps, object detection, object tracking, and relative move of the UAV under control (Lo et al., 2021; Wise & Rysdyk, 2006). The whole structure is shown below (Fig. 4). The UAVs are equipped with both visible and infrared cameras to collect information.

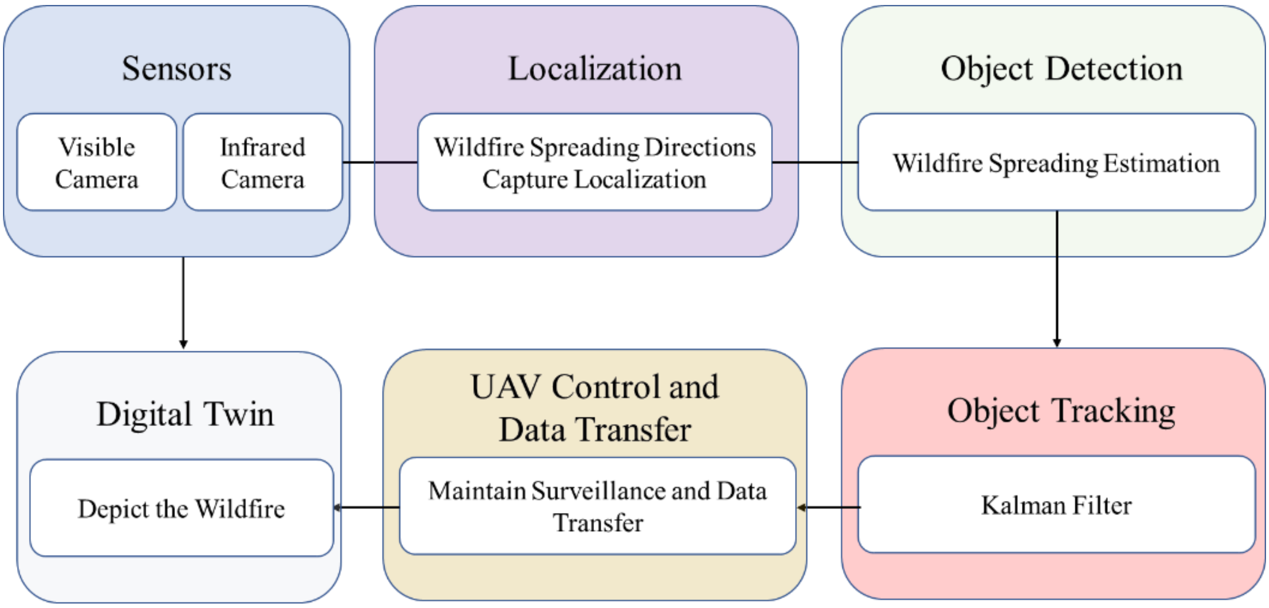

Figure 4- Proposed architecture of autonomous wildfire tracking system

2.1. Fire front detection

Object detection also contains object localization and classification. Compared to traditional algorithms for detecting objects, deep learning-based algorithms have many advantages in robustness, speed, and accuracy. In this study, a deep learning-based approach has been adopted to detect the wildfire front. It is called You Only Look Once (YOLO), which is a state-of-the-art, real-time object detection system. Many researchers (Lestari et al., 2019; Wu & Zhang, 2018) proved the function of YOLO algorithms in fire detection.

Figure 5- YOLO applied in fire detection (Wu & Zhang, 2018)

2.2. Fire front tracking

Fire front tracking is much more challenging than detection due to faced uncertainties and complexities in aspects. Finally, the Kalman filter method (Welch & Bishop, 1995) was chosen to realize the motion association of object tracking. Compared to normal object detection, the major difference is that fire would spread while UAVs have to follow the wildfire front. To solve this issue, thermal infrared cameras would assist in reducing the uncertainties of flame waves. It conveys the temperature information to the tracking algorithm to ensure a correct path.

Figure 6- Wildfire tracking and UAV moves

2.3. UAV control and data transfer

UAVs are controlled based on the ROS software in the Linux system. Then instructions are programmed into the control commands. In terms of data transfer, the image transmission technology of UAVs themselves can build communication with servers.

2.4. Wildfire portrait

Finally, the combination of UAV location information based on GPS and camera view information could be sent to the virtual systems, promoting to depict of the wildfire fronts in the digital twin systems. The positions on the wildfire front would be updated in time to provide information for wildfire decision makers.

3. Conclusions

In this study, an autonomous wildfire tracking system based on UAV swarms is proposed to assist in locating the fire front. As for this work, we applied the YOLO-v5 object detector and Kalman filter to perform target object tracking. It further proposed an efficient UAV planning to achieve a real-time tracking and autonomous surveillance UAV system. The UAVs use an orthographic view to locate the wildfire, controlling and maintaining the gesture with a perspective lock on the wildfire head. Then, UAVs track and follow the wildfire head without human intervention. In addition, the combination of UAV location information based on GPS and camera view information depicts the wildfire in the digital twin systems. This study aims to act as a pre-processing step for wildfire digital twin data transfer. It will provide a basis for the precise wildfire portrait in the virtual systems.

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