Automatic Flight Plan Creation Tool with Digital Twin for Monitoring Forest Fire on Mountain Trail through UAV

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Abstract
A tool for creating flight plan is needed to monitor forest fires on mountain trail through UAV. Existing tools for crating flight plan for forest fires monitoring are created in a file format applicable to Ground Control Station. Additional time and manpower is consumed to apply the flight plan to the UAV. This paper presents AFPC(Automatic Flight Plan Creation), a tool that can automatically apply flight plan of UAV through digital twin. AFPC uses digital twins, so it can be easily expanded to enable UAV state monitoring and prediction using artificial intelligence. The evaluation of the AFPC compares the time and resources spent applying the flight plan created by the tool to UAVs with the related work.

Keywords
Forest Fire, UAV, Flight Plan, Digital Twin,

1. Introduction

A forest fire that fails to respond in the initial stage grows into a large forest fire using surrounding leaves and vegetation as fuel. Since large-scale forest fire cause great damage to surrounding private houses and nature, early detection and response is important. UAVs are suitable for forest fire surveillance because they can reconnaissance over large terrain. Fig. 1 shows the analysis by the Korea Forest Service of the causes of forest fires that occurred in Korea from 2012 to 2021 [1]. The forest fire that occurred in South Korea were caused by artificial factors with a statistical probability of about 70%, and about 34% of them were forest fires caused by trackers.

Based on this, the existing paper presented a tool for automatically generating a flight plan based on a mountain trail for forest fire monitoring through UAV. However, since existing tool creates a file in the format that can be used as the input to the GCS (Ground Control Station), time and resource are required to apply flight plans to UAVs.

This paper presents AFPC (Automatic Flight Plan Creation), a tool that can automatically apply flight plan of UAV through digital twin. AFPC combines digital twin with existing flight plan creation tool, allowing UAVs to perform automatically created flight plan. AFPC uses digital twins, so it can be easily expanded to enable UAV state monitoring and prediction using artificial intelligence. The digital twin used in AFPC was constructed by adding a DB module to the Ditto [2]-based digital twin framework to improve data transmission performance.

The evaluation of AFPC compares the time and resources spent applying the flight plan to UAVs with related work. APFC can reduce time and resource consumption about 6-8 times compared to related work.Also, we evaluation of the AFPC uses Gazebo [3], a flight simulation to confirm that the UAV is flying normally according to the flight plan generated through the AFPC. As a result, it was confirmed that the UAV flew normally according to the flight plan applied through AFPC.

2. Background

2.1. Unmanned Aerial Vehicle

An Unmanned Aerial Vehicle (UAV) is an aircraft that does not have a pilot on board and has a wide range of activities. UAVs consists of various hardware devices necessary for flight and software for automatic flight and state control. Due to their ability to provide efficient infrastructure and a wide range of services, UAVs are increasingly being recognized as a major component of the next generation of smart cities [4].

UAVs can be used for reconnaissance missions for forest fire monitoring. Since large-scale forest fires cause property and personnel injury, it is important to detect and respond to forest fires early through UAVs. UAVs can perform reconnaissance missions for forest fire detection through devices attached to UAVs while traversing the set flight plan. The flight plan of the UAV can be set using the flight plan creation tool. The created flight plan can be applied through GCS. GCS is software for monitoring and controlling UAVs and includes the function to apply flight plans to UAVs.

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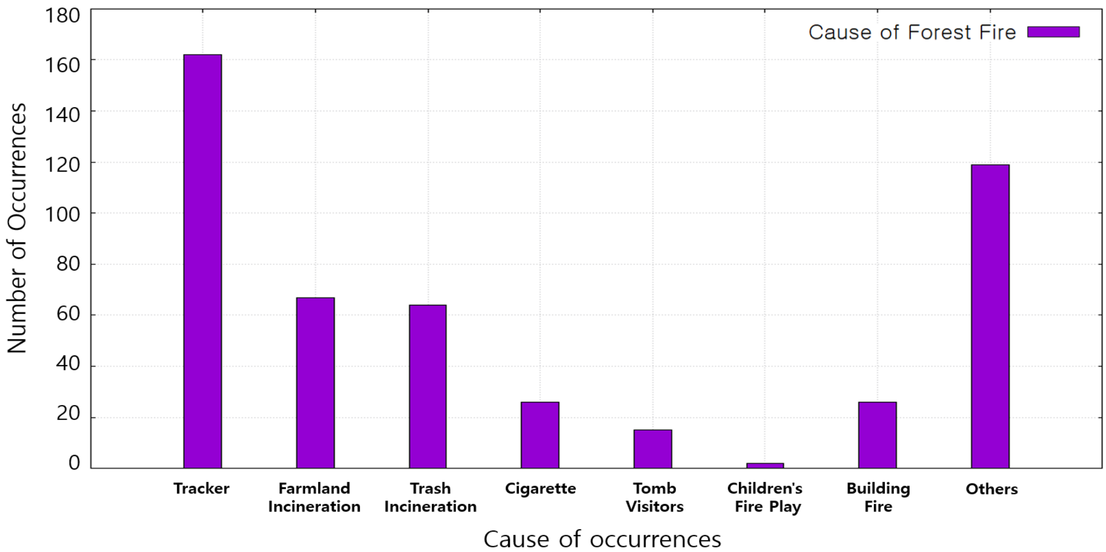


Figure 1: Causes of Forest Fires in Korea between 2012 and 2021 [1]

2.2. Digital Twin

Digital Twin was first introduced by Grieves [5] in 2003 and is a technology that connects physical and virtual spaces. Currently, digital twin is recognized as the core technology of the 4^{th} industrial revolution, and monitoring and simulation can be performed by virtualization things in physical space in virtual space. Recently, research on digital twin technology has been actively pursued as various fields such as big data, ICT (Information and Communications Technology), and cloud computing have advanced [6]. Digital twin is defined as a next-generation simulation technology because it performs monitoring and simulation based on real-time state data of things in physical space.

The digital twin framework provides functions such as data communication and object management. it can enhance the reusability, compatibility, and maintainability of digital twins. Ditto [2], provided by the Eclipse Foundation, is a representative digital twin framework based on open source. Ditto is a framework that provides the functions of a digital twin, and provides functions such as registered things management, communication, and security.

However, Ditto has a limitation of registering up to a maximum of 511 objects and the communicable data size is limited to 100KB. In addition, since Ditto does not manage past data, the Ditto used in this paper is used in conjunction with an additional DB module.

3. Related Work

Ditana et al. [7] have presented a system that can detect forest fires early using UAVs and artificial intelligence. The UAV scans the forest using optical and thermal cameras, and the AI algorithm analyzes the data collected by the drone to detect forest fires, which can then be reported to ground firefighters for appropriate action. Ko et al. [8] proposed a system that uses a UAV equipped with a thermal camera to detect high-temperature areas, process the data in real-time, and provide information that can be used for forest fires prevention. The UAV can transmit information about high-temperature areas to a base station, which can help prevent forest fires from occurring early on. These two works focus on detecting forest fires rather than creating UAV flight plan to detect.

Han et al. [9] and Joo et al. [10] presented a tool to create a flight plan for UAVs that make a reconnaissance around the Mountain trail to monitor forest fire. The presented flight plan creation tool creates a flight plan file in the format applicable to the GCS. Files generated by existing tool have to be applied to UAVs through GCS, which requires additional time and manpower. To reduce the additional time and resource for applying flight plan to UAVs, a tool is need to automatically apply flight plan to UAVs.

4. Solution

This paper presents AFPC (Automatic Flight Plan Creation), a tool that can automatically apply flight plans

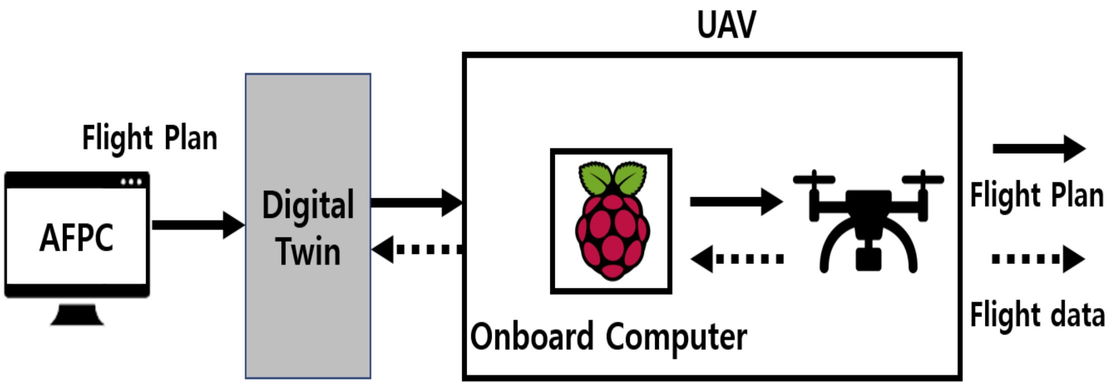


Figure 2: AFPC Overview in UAV Environment

for forest fire surveillance to UAVs. AFPC directly transmits flight plan information to the digital twin instead of creating a flight plan file that can be applied to GCS by applying digital twin to existing flight plan creation tools. The flight plan stored on the digital twin then allows UAVs to automatically read. The digital twin used in AFPC was constructed by adding a DB module to the Ditto [2]-based digital twin framework to improve data transmission performance. The UAV used an onboard computer, a Raspberry Pi, to communicate with the digital twin. AFPC uses digital twins, so it can easily be extended to enable state monitoring and AI-based prediction while UAVs perform flight planning. Fig. 2 shows the overall structure of the system to which APFC is applied and the operation process of AFPC is as follows:

1. First. The user sets up a flight plan based on the Mountain Trail through APFC.
2. Second. The assigned flight plan is transmitted to the digital twin.
3. Third. The UAV reads the flight plan stored in the digital twin through the Raspberry Pi and applies it to the UAV system.

AFPC not only applies the flight plan in the environment to UAV, but also can collect UAV's state data. This allows users to periodically manage the UAV through the digital twin included in AFPC. For example, users can verify whether the UAV is flying the flight path correctly and predict and handle errors that may occur in the UAV in advance. The method of monitoring UAV through AFPC is as follows:

1. First. The state of the UAV is transmitted to the Raspberry Pi.
2. Second. The Raspberry Pi transmits the state of the UAV to the digital twin.
3. Third. The digital twin analyzes and responds to the current state of the UAV through user-defined algorithms.
4. Four. The Raspberry Pi applies the UAV control commands received from the digital twin to the actual UAV.

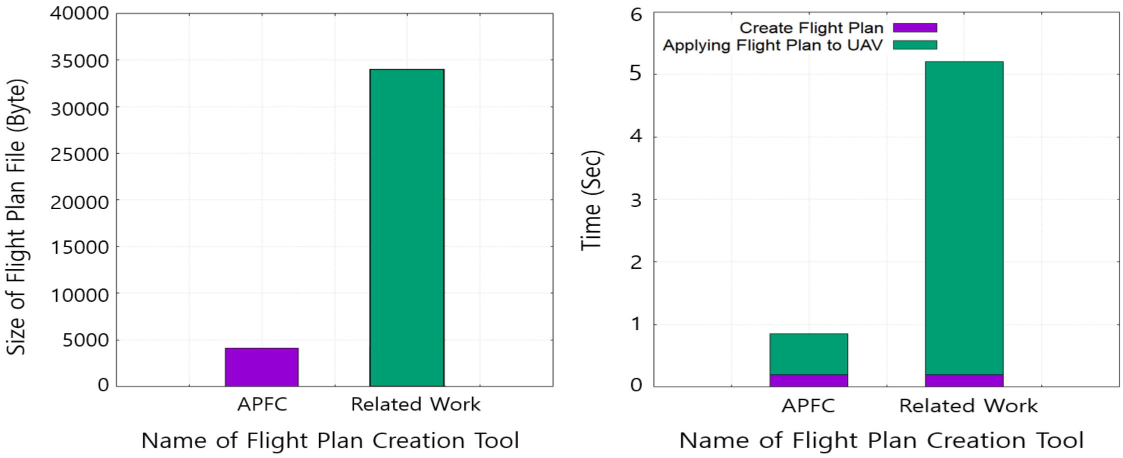
In additionally, the flight plan creation in previous work involved randomly creating waypoints along a specific path. In contrast, APFC applies an algorithm that reduces the number of randomly created waypoints based on distance. As a result, flight plans created by APFC require fewer waypoints to reach their destination compared to existing creation tool.

5. Evaluation

The environment used for the implementation and experiments of AFPC consisted of a PC with Windows 10 operating system, CPU Intel i7-11700, and 32GB RAM. Raspberry Pi 4B module was used as the onboard system of the UAV. In addition, Ditto 2.2V was used, which was built in a Docker environment.

The evaluation of AFPC compares the time and resources spent applying the flight plan to UAVs with related work. (a) in Fig. 3 compares the size of the flight plan file created by AFPC with the size of the flight plan file created by the related work. As a result of the comparison, AFPC created a file of about 4.2KB size when it created a flight plan containing about 110 waypoints, while related work created a file of about 33.8KB size. When using AFPC to create flight plans, flight plans can be applied to UAVs with approximately 8 times smaller data than related work.

(b) in Fig. 3 compares the time it takes to create a flight plan and apply the created flight plan to the UAV. As a result of the comparison, both AFPC and related work



(a) (b)

Figure 3: The Results of Performance Comparison

(a) (b)

Figure 4: The Results of Flight Plan creation through AFPC

took approximately 0.2 seconds to create a flight plan. However, applying the created flight plan to UAVs took approximately 0.65 seconds for AFPC and approximately 5 seconds for related work. In summary, APFC could reduce time and resource consumption about 6-8 times compared to related work.

Additionally, We evaluate the AFPC through simulation that the UAV flies according to the flight plan crated by the AFPC. The simulation is performed in the Gazebo [3] environment, which is mainly used for aircraft. Fig. 4 shows that the UAV is flying according to the flight plan set in the Gazebo. (a) in Fig. 4 shows the applied to the UAV through AFPC, and (b) shows the UAV flying in the simulation environment along the set flight path. As a result of the evaluation, it was confirmed through simulation that the UAV flew normally according to the flight plan set through AFPC.

6. Conclusion

Reconnaissance missions for forest fire surveillance using UAVs are important for early detection and response to forest fires. For forest fire detection, tool is needed to create flight plans for UAVs based on mountain trails. However, existing tools require application to UAVs via GCS, which requires additional time and manpower. This paper presents an AFPC that combines digital twins to automatically apply flight plan to UAVs. As a result of evaluating AFPC, APFC can reduce the time and resource consumption of about 6 to 8 times for applying flight plan to UAVs compared to related work. The simulation results evaluated that the UAV in the simulation flies correctly according to the flight plan applied through APFC.

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