A novel wildfire digital-twin framework using interactive wildfire spread simulator

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Abstract— a wildfire is a serious disaster to destroy an ecosystem and to lose a life of humans. A wildfire simulation can help to reduce damages by supporting a wildfire spread prediction. The existing wildfire simulations have a limitation for exactly predicting actual wildfire spreads because it is difficult and complex to preform simulating with reflecting dynamically changing environmental parameters. Therefore, this paper proposes a novel wildfire digital-twin framework using interactive wildfire spread simulator. The framework is designed to give a wildfire-twin including a wildfire simulator the sensing data gathered from oneM2M IoT server and make the digital twin wildfire prediction.

Key**words— interactive wildfire simulation; digital twin; internet of thing; data assimilation;**

I. Introduction

A wildfire is generated in mountains or forests by human carelessness, arson, and natural ignitions. The disaster caused not only many casualties and fatalities, but also ecosystem degradation such as air pollutions and soil losses [1]. As a recent example, Camp fire which was historically the most damaging wildfire in California occurred in December 2018 [2]. The serious accident destroyed 620 square kilometers of woods and village, 86 people died, 17 people got injured and 16.5 billion dollars of economic losses occurred. One of the methods to reduce the damages caused by wildfire is to navigate people to shelters and to extinguish wildfires quickly through an accurate wildfire spread prediction [3].

Researchers have studied wildfire spread algorithms and fuel models for accurate wildfire spread prediction [4]. A fuel model is made by calculating fuel properties based on variables of a landscape file. The wildfire spread algorithm applies wildfire spread models to change states of fuel models in each cell. By using the wildfire spread algorithm and modeling of fuels, the wildfire simulation creates result files that include the time of arrival, the spread direction, the rate of the fire spread, and so on [5]. The novel wildfire simulations are researched to decrease computation times of simulation and to reduce the differences between the wildfire spread prediction and a real wildfire.

The existing wildfire simulations conduct wildfire spread algorithm and fuel modeling in static environments based on the wildfire data of the past or input data from users. They can be trusted to predict wildfire spread in an environment where the weather changes do not happen frequently or the fuel models are not varied [6]. In contrast to the static environments, real wildfire environments produce unexpected wildfire spread results due to frequent weather fluctuation and various fuel models [7]. The fuel models also may differ from the properties between the specific region and the existing wildfire simulation, which may affect the simulation accuracy [8]. The fuel models and variables about weather fluctuations added to the dynamic environment improve wildfire spread prediction, but the simulation may cause the problems of high complexity and processing time [9]. The simulation in dynamic environments needs some technologies to improve the prediction, complexity and processing times without adding weather variables.

Data assimilation could be applied to improve simulation accuracy in the dynamic environment. It is a technique that filters or adjusts the results by comparing real sensing data with simulation data [10]. To apply it to wildfire simulations, it needs weather environments data which has high alterability such as wind direction, wind speed, and temperature. A digital twin that reflect wildfire environments can satisfy the requirements for data assimilation. The digital twin is an extended cyber-physical systems (CPS) concept, which is a virtual model that accurately reflects state information of physical systems based on real-time IoT technology [11]. Through modeling and simulation (M&S) and AI technologies using digital twin, it is possible to improve system reliability by performing system diagnosis and state prediction. Through the wildfire simulation based on the wildfire digital twin, the simulation that reflects the actual environment could be performed and the result could be corrected to obtain higher simulation accuracy.

This paper proposes the wildfire digital-twin (WF-DT) framework for simulation based on the sensing data in oneM2M IoT server. The framework provides sensing data-set collected in oneM2M IoT server and the results of the interactive wildfire (I-WF) simulator which is developed to use sensing data. This paper is composed of as follows. In section 2, related works of the wildfire simulation and data assimilation are discussed. Section 3 introduces WF-DT framework and I-WF simulator. Finally, this paper discusses the conclusion.

II. RELATSED WORKS

A. *Wildfire simulation*

Wildfire simulations define mathematical models of fuel moistures, geographic, and weather. The models are truly proved by wildfire experiments in real-life environments and simulation [12]. The simulators based on these models calculate wildfire spread algorithm about wildfire spread types which include a crown fire, surface fire, and spot fire for each time-stamp [13]. The wildfire simulations have a raster and vector type [9]. The vector type simulator features elliptical wave propagation of wildfire, provides the high accuracy of wildfire spread, and has disadvantages of high processing delay and complexity. The raster type simulator divides a map into cell units and calculates the cells with wildfire spread algorithm. It has lower processing time and higher simulation complexity, less accurate than the vector type simulator. Although both simulation types have different advantages, they are inaccurate to apply to the dynamic real wildfire environment.

Data assimilation technologies could be used to enhance the accuracy of a wildfire simulation. *Xue* proposed the data assimilation to compare the results with the temperature sensed at the wildfire using the sequential monte carlo method [6]. The fire front states are defined through the simulation of DEVS-FIRE. A multivariate Gaussian distribution to filter burning cells is generated by the measurement model and the temperature data in each cell. After that, it is distinguished whether or not the cell is burning through the resampling of the multivariate Gaussian distribution. *Fu* proposed data assimilation method for simulation of wildfire collected in a wind direction and wind speed [14]. *Fu* makes a normal distribution that compares wind speed and wind direction with the real data and the measurement model of simulation. The simulation performs resampling wildfire states to each cell. In this paper, we propose a framework that supports simulations on the data assimilation using sensing data of real wildfire situation in order to increase the accuracy of the simulation.

III. WILDFIRE DIGITAL TWIN FRAMEWORK

A. *Wildfire Digital Twin Framework*

The architecture of WF-DT framework is shown in figure 1. WF-DT framework is composed of WF-DT instance pools and a WF-DT service platform. The WF-DT instance pools perform instantiation based on sensing data which is transferred to IoT-DT interworking function in the WF-DT service platform. It also requests data or library-set in the platform to support services such as WF-DT instance management, wildfire visualization. The WF-DT service platform acquires periodically the sensing data collected at oneM2M IoT server and gives dataset for operating services of WF-DT instances (e.g. wildfire spread prediction results, real sensing data). The platform has four modules: IoT-DT interworking function, WF-DT lifecycle management, I-WF simulation engine, and I-WF simulation interface.

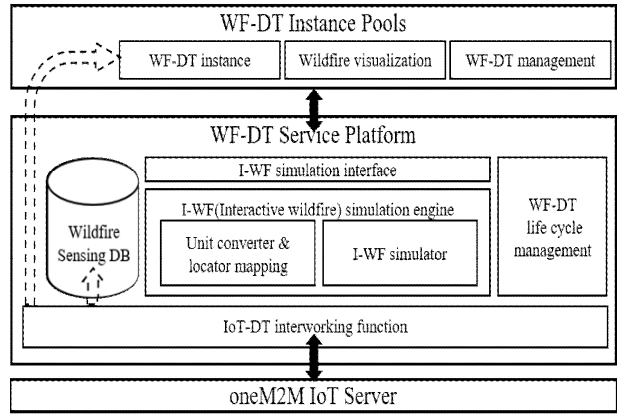

Figure 1. The architecture of the WF-DT framework using I-WF simulator

1) IoT-DT interworking function

This module sends sensing data from oneM2M IoT server to a WF-DT instance. It periodically requests stored sensing data from oneM2M IoT server. The receiving data are stored at the wildfire sensing DB in WF-DT service platform. The module helps WF-DT instances take the data when they request the stored data at the module.

2)WT-DT lifecycle management

This module manages construction and deconstruction of WF-DT instances. The WF-DT manager commands to control resources of the WF-DT instance pool and manages wildfire simulation process using this module.

3)Interactive wild-fire simulation engine

This module performs the wildfire simulation and produces to spread simulation result. The unit converter converts the units of instances input data to units of simulation input data. The location mapping performs matching with simulation cells to check if the cells are in the simulation engine.

4)Interactive wildfire simulation interface

This module helps to connects WF-DT instances to I-WF simulation engines. The connection enables sending the sensing data of the instances to input data of I-WF simulation and transferring the simulation results to WF-DT instance.

B. *Interactive wildfire simulator*

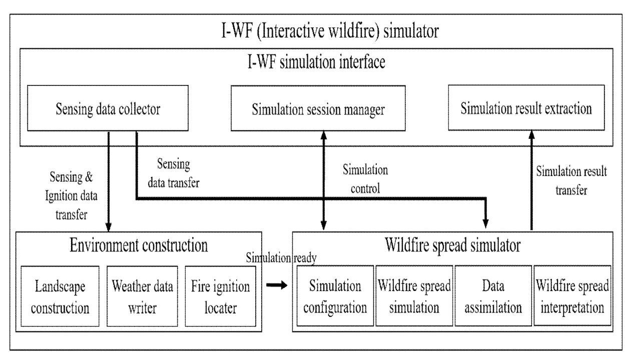

Figure 2. The architecture of the I-WF simulator

The figure 2 shows the architecture of the I-WF simulator. The simulator is composed of the I-WF interface, environment construction, and wildfire spread simulator. The I-WF simulation interface transfers input data of WF-DT instances to the landscape construction, communicates messages to control with the wildfire simulation, and gets simulation results by computing wildfire spread simulator. The environment construction sends simulation input data like terrain, weather and ignition point to the wildfire spread simulator. The wildfire spread simulator transfer predicted result data to the I-WF simulation interface.

1) Interactive wildfire simulation interface

The I-WF simulation interface helps instances to connect with the I-WF simulator and to control the simulation operation by messages. This module is composed of the sensing data collector, simulation session manager, and simulation result extractor. The sensing data collector receives sensing data collected from WF-DT instances. The simulation session manager commands a pause and resume of the wildfire simulation when the sensing data gets new sensing data. The simulation result extractor sends ouput results of the wildfire simulation to WF-DT instances.

2) Environment construction

The environment construction makes wildfire environments files combining GIS(geographic information system) and the sensing data. It consists of the landscape construction, weather data writer, and fire ignition locator. A role of the landscape construction is to store a landscape data such as elevation, canopy layer, fuel model, slope, etc. The wildfire ignition locator chooses ignition points which invoke wildfire based on sensing data, for locating ignition of the wildfire simulator.

3) Wildsfire spread simulator

The wildfire spread simulator performs the wildfire simulation with the data which are constructed by the landscape construction module. The module has the simulation configuration, wildfire simulation, data assimilation, and wildfire spread interpretation. The simulation configuration sets simulation durations, and timestamps, etc. The wildfire simulation simulates wildfire spread algorithms which are defined as mathematical models of environments. The data assimilation corrects wildfire results by predicting wildfire spread using sensing data like temperature, wind speed, etc. The wildfire spread interpretation creates files that have results of the fire spread simulation like times of arrival, rates of spread, etc.

IV. Conclusion

This paper proposed WF-DT framework to serve accurate prediction of wildfire spreads using I-WF simulator. When applying the existing wildfire simulations to dynamic environments and various fuel models caused inaccurate prediction of wildfire spread. WF-DT service platform was proposed to apply the data assimilation technique based on the sensing data to improve the simulation accuracy in the dynamic environments. WF-DT service platform helped the data assimilation through the sensing data stored in oneM2M IoT server, and the performance of I-WF simulator for accurate wildfire spread prediction. With this framework simulating dynamic environments with sensing data, the reduction of human casualties and ecosystems degradation by proper wildfire defenses can be expected.

Acknowledgment

This research was supported by the Institute for Information & communications Technology Promotion (IITP) (No. 2015-0-00816-005 and No. 2018-0-01456-002).

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