Mobile Architecture for Forest Fire Simulation Using PhyFire-HDWind Model

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Abstract. This article presents the design and implementation of a new visualization system for mobile platforms for the PhyFire-HDWind fire simulation model, called AppPhyFire. It proposes a mobile computing infrastructure, based on ArcGIS Server and REST architecture, which improves the user experience in actions associated with the fire simulation process. The PhyFire-HDWind model, of which the system presented here forms part, is a forest fire propagation simulation tool developed by the SINUMCC research group of the University of Salamanca, based on two own simplified physical models, the PhyFire physical fire propagation model, and the HDWind high definition wind field model, resolved using efficient numerical and computational tools and parallel computing, allowing simulation times shorter than the real time fire propagation, integrated into a Geographical Information System, and accessible through a server by the AppPhyFire. The system presented in this article allows a quick visualization of simulations results in mobile devices. This work presents the detailed operation of the system and its phases of operation.

Keywords: Simulation · Mobile architectures · Prediction models · PhyFire · HDWind

1 Introduction

Indonesia in 2015, Canada and Spain in 2016, Chile and Portugal in 2017, Greek and California in 2018, are just some examples of how forest fire is a global problem that is getting worse due to several factors. One of these factors, is the devastating impact of climate change. Wildfires are more severe, more intense and longer lasting, causing more loss of life and property.

The scientific community makes efforts to seek solutions for this growing problem, relying on emerging technology, seeking ways of adapting, preventing and combating forest fires. An example of these efforts are the numerous forest fires spread models existing (FARSITE [1], Prometheus [2], WRF-Fire [3], etc.), and how current technologies (Geographical Information Systems, Remote Sensing, Supercomputing) are improving the applicability and efficiency of these models. The introduction of

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programming techniques for the use of multiprocessor systems has allowed a significant increase in the computing capacity of the simulations tools based on these models. Moreover, current computational technology offers great potential for the effective modeling of wildfire behaviour through more complex models.

Mobile computing is also being using as a useful tool in firefighting, such as an early warning system for wildfire alerts [4] or to view active fire maps on mobile devices [5]. But predicting fire spread and behaviour on a wildfire, in the field through a mobile device, can be determinant in order to minimize many risks for firefighters, to improve the success of their work and prevent the loss of human life. Some experimental wildfire spread systems have recently developed mobile applications [6]

We present here a system that allows a quick visualization of the simulations performed in SINUMCC Server thanks to the fusion of physical simulation models (Phyfire and HDWind server models) and current communication and data processing technologies (such as Api REST, JSON and ArcGIS Server). This article presents the detailed communication with the system and its operation phases for a mobile app: AppPhyFire.

The rest of the paper is structured as follows: Sect. 2 presents a background about the prediction models and technology used. The proposed system is described in Sect. 3. Finally, results and conclusions are summarized in Sect. 4.

2 Background

Wildfires are a growing problem and the climate change with higher temperatures and drier landscape increase their frequency and severity. Wildfires are not only due to the outcome of climate change, they also emit greenhouse gases and therefore also contribute to global warming.

In recent years, thanks to the technological advances, there has been an increasing development of wildfire spread models. The simulation of wildfire spread has direct applications in prevention and firefighting, from risk mapping, reforestation policies, to evacuation planning or resource optimization. There are several types of wildfire spread models, that range from the purely physical (based on physical and chemical principles involved in the combustion of biomass fuel and behaviour of wildfire) to purely empirical (based on phenomenological description or statistical regression of observed fire behaviour) passing through approaches from one end of the spectrum to the other [7, 8]. All kind of models should try to strike a balance between fidelity and fast execution to be operational. The use of empirical models, most of them based on Rothermel's model [9], is widespread due to its simplicity and computational efficiency, but their applicability is limited. Physical or semi-physical models are more complex and has high computational costs, but the current computational technology offers great potential for the effective modeling of wildfire behaviour through more complex models.

The PhyFire-HDWind model, upon which the mobile architecture presented in this paper has been developed, is a wildfire spread simulation tool developed by the research group SINUMCC at the University of Salamanca, based on two own simplified physical models, the physical fire spread model PhyFire, and the high definition wind field model HDWind, solved making use of efficient numerical and computational tools and parallel computation, allowing simulation times shorter than the real time of the fire spread.

2.1 PhyFire-HDWind Models

The PhyFire model is the current version of a simple 2-D one-phase physical fire spread model first published in [10], based on the energy and mass conservation equations. This model considers convection and radiation as dominant thermal transfer mechanisms, and mainly depends on metheorological data (direction and intensity of the wind, ambient temperature and humidity), orography, and fuel type and load. The influence of fuel moisture content and heat absorbtion by pyrolysis is considered by means of a multivalued operator representing the enthalpy [11]. Radiation is represented by a non-local radiation term that allows the modelling of the radiation from the flame above the fuel layer, enabling to cope with the effect of wind and slope over the flame tilt [12]. Efforts have been made to improve the feasibility of the PhyFire model with simulations of real fires [13], and experimental fires [14]. The simulation of experimental examples has been used to perform a global sensitivity analysis of the model allowing to conclude that the model properly reflects the most important factors affecting a wildland fire spread, to configure the design of model parameter adjustment, and to improve and update the model itself.

The numerical methods used to solve the non-dimensional equations derived from the model, include finite element method combined with different finite difference schemes. In addition, the computational cost has been reduced by means of definition of active nodes and making use of parallel computation techniques in order to become competitive compared with some other simpler models. The model code is programmed in C++, using the API OpenMP in order to take advantage of the multiprocessor platforms to reduce the computational time [15]. It was compiled using the GNU Compiler (GCC) version 4.6.3.

PhyFire can operate with constant wind or with wind data provided by a wind model, particularly with wind data provided by the HDWind model. HDWind is a mass consistent vertical diffusion wind field model. The idea behind this model is to adapt the principles of the shallow water models, where the horizontal dimensions are much larger than the vertical one, to the forest fire convective phenomena. Through an asymptotic approximation of the primitive Navier-Stokes equations, this model provides a 3D velocity wind field (which satisfies the incompressibility condition) in the air layer under the influence of the fire, by solving only 2D linear equations, so that it can be coupled with the 2D PhyFire model. The 2D equations of the HDWind model depend on the temperature surface distribution, the surface height and the meteorological wind flow on the surface boundary. The model depends on a single parameter, the air friction coefficient which is related with the roughness length of the surface. The nonlinear terms are neglected and it is assumed that the air temperature decreases linearly with the height, however, the model takes into account buoyancy forces, slope effects, and mass conservation [16]. Last version of HDWind [17] allows to obtained a wind field that fits to several punctual wind velocity measurements at different points in the 3D domain (the air layer) by an optimal control problem in which the wind flow on the surface boundary is the control.

Both models, PhyFire and HDWind, can be compiled for any platform, and can operate either together or separately. In order to automate the processes of input data capture and output data visualization during the simulating process, PhyFire and HDWind have been integrated into a Geographic Information System [15]. This GIS-based interface has a dual purpose, on the one hand, this provides a more accessible tool to a broader audience that might not be familiar with the models; and on the other hand, this facilitates the testing and validation process. The PhyFire integrated in the GIS tool uses the following input data: topography, fuel load and type, weather conditions, ignition location and fire suppression tactics; and predicts the fire spread for the established time period. The outputs provided at each time steps are: the burnt area perimeter and the fire front position and depth. Likewise, the HDWind integrated in the GIS tool also uses topography, surface roughness and weather conditions, and provides a wind velocity field that is well adapted to the domain studied. Both have been developed for its use throughout Spain, so the scope of the spatial information currently used is limited to that area. For this purpose, a geodatabase has been developed containing the three maps needed for extracting the spatial information our models use: a first map containing the height of the surface, a second map gathering all the information related to fuel type, both maps used by the two models, and a third map collecting all the elements involving the function of either artificial or natural fuel-breaks that affect the fire spread, only used by the PhyFire model [18]. This geodatabase has been generated from several public map service as the Spanish National Geographic Institute or the Ministry of Agriculture, Food and Environment of the Spanish Government.

The GIS tool chosen for this integration was ArcMap 10.4 of Esri's ArcGIS Desktop suite and the interface was developed as a Python add-in for ArcMap. The functionality of each tool was implemented as a script using the Python programming language and the ArcPy geoprocessing library.

Mobile technology is having a very strong growth at present. Since computing power is limited in these devices, an architecture for offering the PhyFire and HDWind models has been designed via web services, so these devices can easily consume the model operations over the Api REST deployed in a server, https://sinumcc.usal.es/.

3 Proposed System

The PhyFire and HDWind server models have a loose coupling approach, where the linkage between the GIS and the modelling system is made through the import–export of data, specifically ASCII grid text files as inputs and outputs.

Thus, it is key to understand the phases that the tool performs in each simulation: Input spatial data, pre-processing, processing and visualization (Fig. 1).

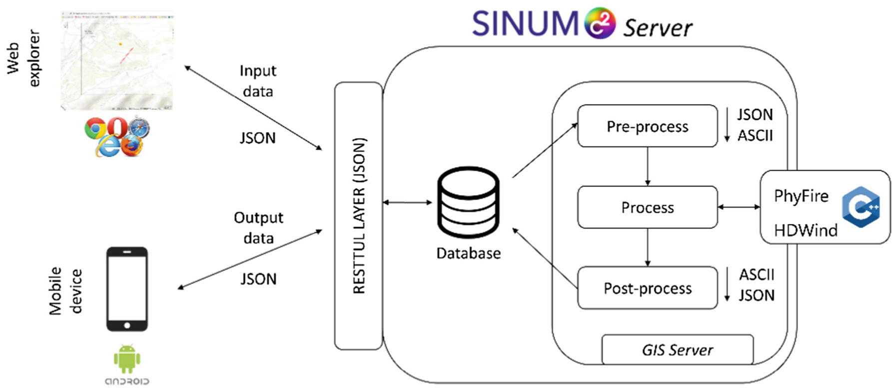


Fig. 1. SINUMCC server architecture overview

3.1 Input Spatial Data

The PhyFire-HDWind tool displays to the user a base map, where the simulation area must be selected. In addition, the user must enter other data such as fire source, lines of defense (optionally), ambient temperature, humidity and wind (speed and direction). Wind data can be constant for the whole domain or can be a collection of punctual data (direction and intensity) in several points of the domain. If constant wind is established, only the PhyFire model is executed, whereas when wind point data are entered, the HDWind model calculates a wind field over the simulation area that best fits these punctual data, so the simulated wind field will be used as wind data in the PhyFire model. The simulation time can also be set by the user. All these data are collected and saved in a database server in JSON format identified by an ID of the simulation.

3.2 Pre-process

Once desired data has been stored in the server, the PhyFire tool takes JSON saved data and start making transformation for obtaining three files corresponding to the topography, fuel type and fuel load of the study domain, in order to get the georeferenced data necessary for the simulation [18]. Therefore, it is enough to clip these data corresponding to the study domain from the geodatabase developed for this purpose, described above.

3.3 Process

Once all the input data for the selected area are pre-processed, clipped, checked to avoid errors, converted to raster and exported to ASCII grid text files, the PhyFire and eventually the HDWind model read the files they need, and the simulation is run providing the corresponding output ASCII grid text files.

The PhFire model provides two types of output data: the solid fuel mass fraction and the non-dimensional solid fuel temperature. These data are also stored in ASCII files that collect the rasters of these variables on each point of the simulation area mesh, and at every moment of time in which a graphical representation is required. Comparing the output solid fuel mass fraction with the initial fuel mass fraction inputted into the model provides the state of the landscape. So for each point of the domain we can determine whether or not that specific point has been burnt, defining the fire perimeter. The non-dimensional solid fuel temperature allows to determine the active fire front, its position and depth.

3.4 Post-process and Results Display

ASCII files with the output data from the simulation require a transformation in order to be displayed in their corresponding cartography. Therefore, the ASCII data generated by the models are transformed by GIS operations to finally obtain a JSON file containing a representation of the results.

The data are stored in the database as a result of the simulation using the previously indicated identifier. These data stored in JSON will be used to visualize the results on the map (Fig. 2).

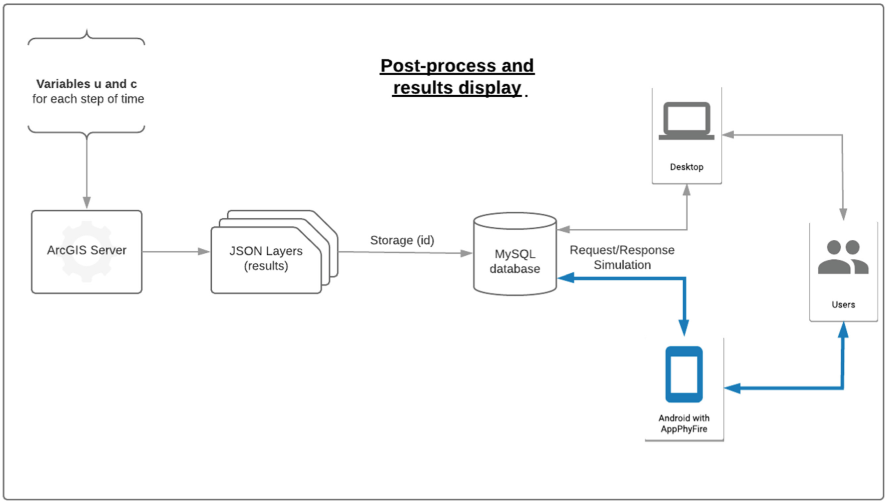


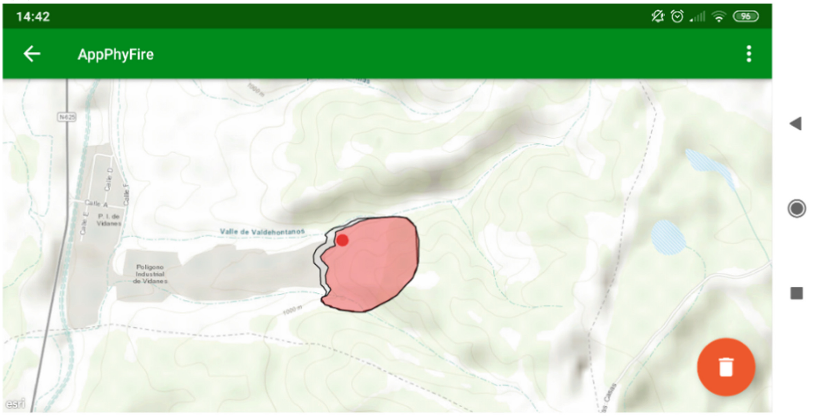
Fig. 2. Data flow diagram. Post-processing and visualization phase.

Due to ArcGIS Server's ability to generate the simulation layers in JSON format, we can use its Android API to collect and show them to users on their terminals with the application installed, thus leaving the framework of traditional devices. AppPhyFire is thus integrated with the rest of the PhyFire system and manages to show users any simulation they have made, giving numerous additional advantages such as the ability to view it from the action area itself and thus improve data capture or validation of existing data.

4 Results and Conclusions

The final system can represent both demonstrations of how the physical models work and the simulations performed by the user, for example, the one shown below (Fig. 3):

(a)



(b)

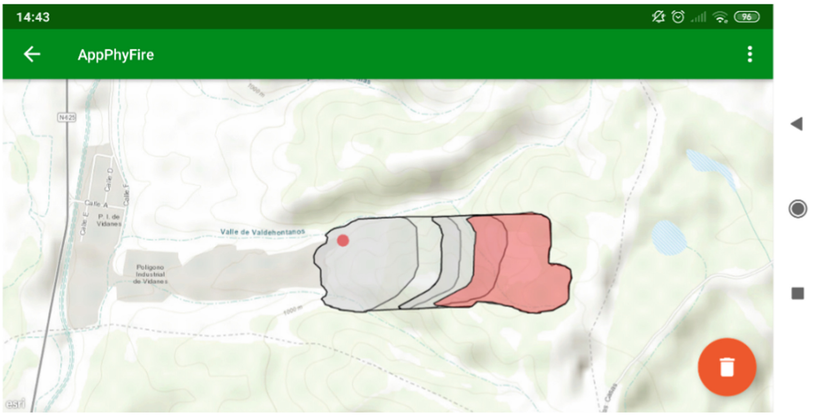


Fig. 3. Displaying PhyFire spread simulation results in the AppPhyFire (a) 1st step. Simulates 0:30 h of fire spread. (b) 4th step. Simulates 2 h of fire spread. It's also showed the intermediate steps (0:30 h, 1 h, 1:30 h, 2 h).

This is a simulation that has four half-hour time steps each and, in each step, there are two layers, a layer corresponding to the position of the fire front (showed in light red on previous pictures) and another layer corresponding to the burned area (showed in light gray). The focus (or focuses) identifies the ignition point of the fire begins, and it is possible to add defense lines that have been also included as an input of the simulation.

The part of hardware or physics necessary for the start-up of the application, as well as all the existing relationships between them, is shown in the following deployment diagram (Fig. 4):

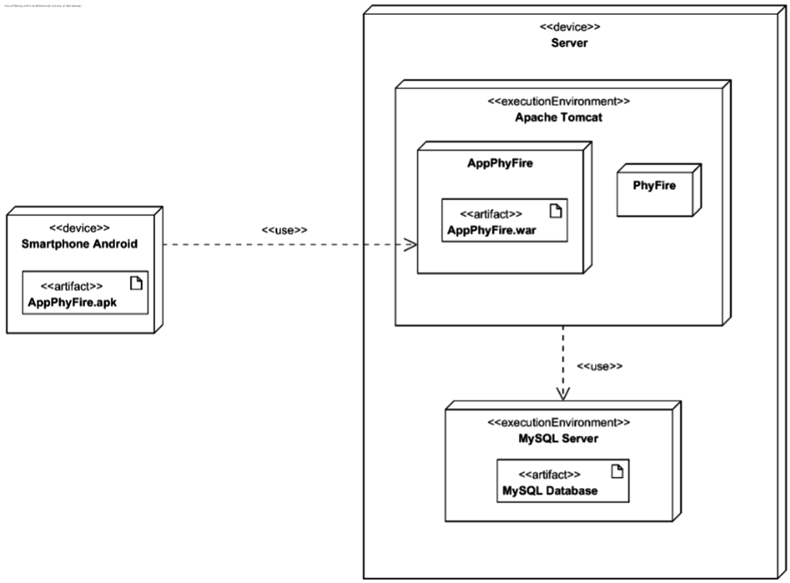


Fig. 4. System deployment diagram

This article describes the different techniques that have been used to create an innovative mobile display system for fire simulations that involve a high computational cost. After a detailed study of the existing technologies our proposal consisted in joining ArcGIS and REST architecture for the visualization of the simulations. The necessary infrastructure was implemented for the introduction, preprocessing and processing of the simulation data, with the aim of creating a light, well-structured, scalable system adapted to the user.

In order to test the stability of the system, visualization requests have been simulated from a mobile terminal to the server. For this purpose, 1000 requests have been made, corresponding to a login request and the loading of a simulation with 4 time steps, with a delay of 1 s between each of them, resulting in an average of 542 ms in obtaining the response and with no loss. The server specifications are: Windows Server 2016, Intel Xeon E5-2660v4 256 GB RAM; The mobile device is a Pixel 2XL with Android 9 over a 4G network.

In a future work, the data that is collected and fed to the server that carries out the computation of the models, could be modified in real time, with what entails a visualization of the simulations in a dynamic way. Given the processing capacities of the current light devices, it is possible to unload the weight of the computation and do it in a more distributed way. The professionals dedicated to fire prevention constantly deal with simulations information and prediction models knowledge. Because the proposed system can be executed on mobile devices, simulation data are always available, and can provide ubiquitous access for the users. These kinds of devices allow the system the use of several context-aware technologies [19, 20] to acquire information from users and their environment. For instance, in the future it would be possible to add mobile alerts, identification or positioning services. Moreover, it is also expected to validate the system with new sources of simulation data.

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