A Real-time Web-based Wildfire Simulation System

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***Abstract*—In order to simplify current fire simulation models for more wide-spread use, a Real-time Web-based Wildfire Simulation System (RWWSS) was developed. RWWSS is a web-based application that provides free access to exploring wildfire simulations. It was developed as an educational tool for the purpose of helping people understand the mechanism of fire propagation and its key impact factors, as well as for motivating fire prevention efforts. The model was implemented using the geography of the Lehman Creek watershed, Great Basin National Park, Nevada, USA. Through numerical simulation of fire propagation, the features of fire intensity, direction, and duration, based on the key factors of slope, wind, and vegetation type are estimated and presented on a 2D map. The user can change these key factors, making the application interactive. With improvements to the model RWWSS could be used for further research purposes.**

Keywords—fire simulation; web-based application; real time; education; RWWSS.

I. Introduction

The explosive development of social-economics is straining food, energy, and water resources around the world, raising serious considerations of how to relieve the conflict between human benefit and environmental security and how to conserve natural resources in the most effective and efficient way. Wildfires can destroy environmental habitat and also endanger human lives and properties. Every year, there are 60,000 to 80,000 wildfire incidents across the United States, burning 12,000 to 40,000 km^2 of land [1], [2] costing more than $900 million in forest fire suppression (on average from 2002 to 2012). Fire suppression costs more than 1/3 of the total federal wildfire protection funds every year, while not including the life lost during the effort of firefighting, as well as extensive losses in individual properties and natural resources [3], [4]. However, 90% of wildfires are started by humans' ignorance of fire danger concerns, as reported by the National Park Service [5].

To the public, an effective fire simulation system that focuses on causes and effects of fire propagation would be of great help to better understand fire propagation factors and their determined behaviors, such as rapid fire spreading rates that occur with the wind direction or with steep topography. In this way, the severity of fire danger can be conveyed during educational scenarios, thereby to prevent ignorance of fire-use precautions. More importantly, to wildfire managers, the fire propagation prediction provided by a simulation system can increase the effectiveness of fire suppression efforts and potentially reduce the cost occurred fighting a wildfire. For instance, an exemplary wildfire simulation can be used in training courses where firefighters can practice hypothetical fires on modeled scenarios before fighting a real wildfire [4].

An ideal training tool for educational purposes involves open access and easy operation with little requirement of other technical skills. With a hands-on explorative fire simulation, the importance of fire prevention can be emphasized and motivated. Current advanced fire simulation models require an operation platform, programming language skill, and large data processing requirements, making them too complex to be used as educational or training tools in many contexts.

Therefore, a simplified model of fire propagation simulation was developed in this study. The Real-time Web-based Wildfire Simulation System (RWWSS) is a web-based application using the client-server architecture. The key factors of slope, wind, and vegetation type are considered within the algorithms that determine fire propagation direction, intensity, and duration. This tool was implemented using the Lehman Creek watershed, Great Basin National Park, in eastern Nevada, and can be directly used as an open source program [6].

The remaining of this paper is organized as follows: Section II provides details of relevant characteristics of the geographical area used in this study; Section III introduces several existing fire models and presents the basic model used in RWWSS; Section IV describes in detail the RWWSS fire simulation tool; Section V compares the proposed tool with similar wildfire simulation applications; and Section VI draws the paper's conclusions and outlines plans for future work.

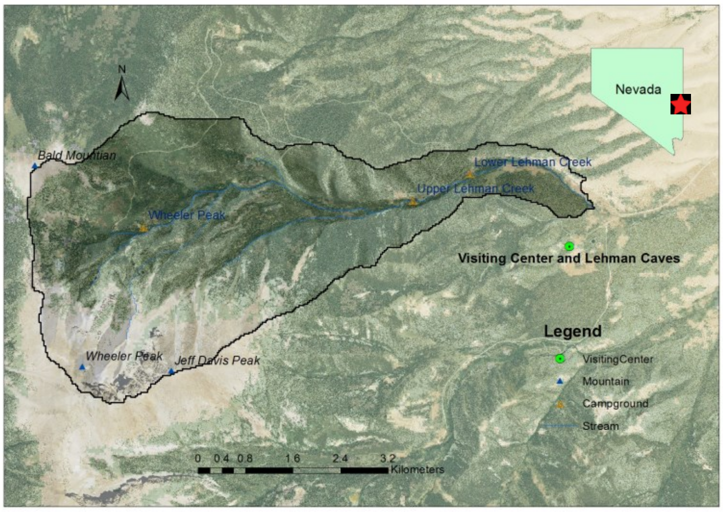

Figure 1. Lehman Creek watershed

II. Study area

The Lehman Creek watershed, shown in Figure 1, drains 23.6 km^2 and is located within the semi-arid Great Basin region, its land cover is mostly undisturbed as it is situated within the Great Basin National Park [7], [8], [9].

The watershed exhibits high topographic relief ranging from 2039 to 3980 meters at Wheeler Peak. Steep topography results in a range of climates and vegetation from mountain peaks towards the floor of Snake Valley to the east. High-elevations consist of a cold and wet alpine tundra transitioning to subalpine and mixed conifer forests in mid-elevations; low-elevations consist of hot and dry pinyon-juniper woodlands [8],[9]. Geology at high-elevations consists of low-permeable massive quartzite overlain by glacial deposits. At lower elevations karst and fractured limestone geologic units begin to emerge [8], [9].

Streamflow is predominantly generated by snowmelt from the high-elevation alpine and subalpine regions and flows east across an alluvial fan [8],[9]. Mean daily streamflow is 0.15 m^3/s, based on stream flow gauging measurements taken intermittingly by the United States Geological Survey (USGS) between 1948 and 2010. The greatest flow is in June, and the lowest flow is in winter (January and February) [9].

Figure 2 shows Wheeler Peak.

Figure **2**. Wheeler Peak from the northeast [12]

III. Fire Models

A. Existing Models

Fire specialists have proposed several different mathematical models, including empirical, semi-empirical and theoretical [13]. Among all models, the most widely used model was developed by Richard C. Rothermel [14] and is a semi-empirical model, depicting fire spreading in an elliptical shape with 11 fuel types. Several fire spreading simulators were developed on the basis of Rothermel's work: BEHAVE [15], developed in 1986, predicting fire burn using the fuel models in Rothermel's paper; FireLib [16], an open source forest fire library with flexibility of the fire propagation method; FARSITE [17], a full-scale fire simulator with the most advanced features, e.g. surface fire, crown fire, spotting and fire acceleration; and FIRETEC [18], developed by Los Alamos National Laboratory using theoretical models of heat transference and chemical reaction to depict fire propagation.

B. The RWWSS Model

Our goal was to create a real-time, web-based application that can serve for education purposes. Because it is hard to fully leverage hardware power from a browser, the model implemented is a simplified version of the traditional fire models. Nevertheless, our simplified model still presents realistically how vegetation types, wind, and elevation affect fire burning and the spread speed.

The spread rate and direction are important for fire spread simulation. The fire burn distances are modeled on a 3 x 3 grid. The center is the on-fire cell. The fire can spread in eight directions: west (left), north-west (left top), north (top), north-east (right top), east (right), south-east (right down), south (down), and south-west (left down). The fire burning distances are the distances between the centers of each cell. The positive spread rate R is calculated as:

$$R = \left|\frac{Rveg*Wind}{\cos(slope)}\right|,$$

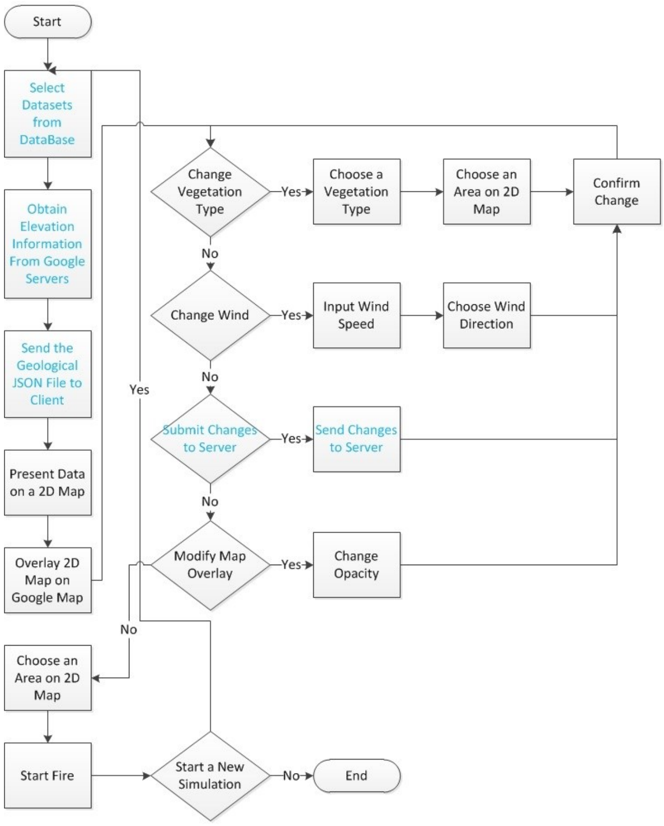

Figure 3. Fire Simulation Workflow (blue words indicate server side; black words indicate client side)

where R_{veg} denotes the vegetation type. Our model includes four types of vegetation: bare ground, grass, shrub, and tree. Based on [19], bare ground spread rate is 0m/h; grass spread rate is 3955m/h; shrub spread rate is 70m/h; tree spread rate is 2533m/h. We used the normalized values (between 0 and 1) in our model, which are 0 for bare ground, 1 for grass, 0.0177 for shrub, and 0.6405 for tree. *Wind* denotes the wind speed (between 0m/s and 100m/s), which is normalized between zero and one. *Slope* denotes the angle between the two cells. *Cos(slope)* is obtained as:

$$\cos(slope) = \frac{BD}{\sqrt{BD^2+\Delta E^2}},$$

where ΔE denotes the elevation difference between two cells, and *BD* denotes the burning distances.

Fire burning indicates the vegetation burning rate. It is used to calculate the burning out time of each cell. Fire burning is determined by the product of vegetation type and wind speed:

$$FB = Veg * WindEff.$$

Here, *FB* denotes the fire burning and *Veg* denotes the vegetation type effect. We used 3 for grass, 2 for shrub, 1 for tree, and 0 for bare ground. *WindEff* denotes the wind effect, which is wind speed normalized between 0 and 10. Since our values where empirically chosen, we are aware that the parameters for the fire burning equation are not very accurate. We aim to improve these values in the future by extracting more precise values from the fuel models introduced in [14].

IV. FIRE SIMULATION TOOL

This section introduces the workflow and basic functions of RWWSS, including how to change vegetation types and the wind speed, set fire, and modify the Google Map overlay.

RWWSS is a web-based application using client-server architecture. We used HTML, JavaScript, and JQuery to build the front-end. Users do not need to install any software to use this tool, and they can explore its related website with any device such as a mobile phone or a tablet.

A. Workflow

Because RWWSS is for educational purposes, it is important that our fire simulation tool has an intuitive and simple workflow. Figure 3 shows the application workflow. The application has two parts: front-end (client side) and back-end (server). Datasets are stored in the server side database and the data is transferred as a JSON file to the client side. Users can use the interface to change the values of vegetation and wind, and save them in the database.

B. Geographic Representation

RWWSS can be used for any location, as long as the JSON file sent from the server has the right format. We use Lehman Creek data as an example to present how basic functions work for this geography. Land cover datasets of canopy, vegetation, and impervious area are from the National Land Cover Database [20] at a 30-meter resolution. The land cover includes 16 types of vegetation: barren land, cultivated land, deciduous forest, developed (high intensity, low intensity, medium intensity, and open space), emergent herbaceous wetland, evergreen forest, hay/pasture, herbaceous, mixed forest, open water, perennial snow/ice, shrub/scrub, and woody wetland. They are further grouped into four categories □ *Bare Ground, Grasses, Shrubs*, and *Trees* □ for use in other hydrologic models, such as the Precipitation Runoff Modeling System (PRMS) model [21].

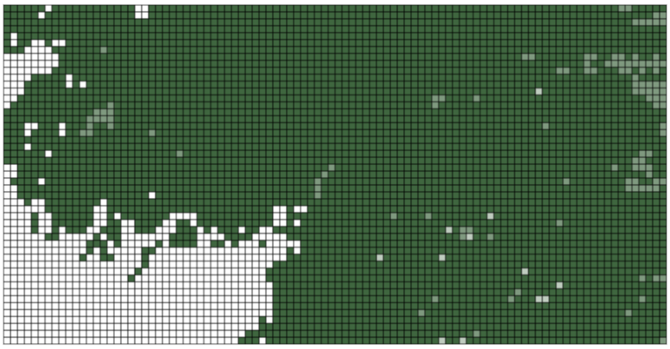

Figure 4. 2D Map

The front-end presents the JSON file sent from our server as a 2D map, illustrated in Figure 4. The JSON file contains information about vegetation types, wind speed, wind direction, and latitude/longitude information. RWWSS can obtain the elevation information of each cell from Google servers. Users can customize the cell resolutions; for example, they can specify that each cell represents 100 x100 meters. The color of each cell indicates the vegetation type: white for bare ground, light green for grasses, green for shrubs, and dark green for trees, as shown in Figure 5.

Figure 5. Color Keys for Vegetation Type

C. *Functions*

Once the 2D map is presented, the user can change the vegetation or wind or modify the map overlay.

There are three steps to changing the vegetation types on the map. First, a vegetation is chosen by pressing the corresponding radio button. Second, the user selects an area by dragging and releasing with the left mouse button. RWWSS then displays the chosen area with yellow. Third, the user clicks the "Confirm Modification" button. Then, RWWSS modifies the area with the chosen vegetation type. The user can save these changes into the server database for further research. Figure 7 shows a vegetation modification in the red circle area.

The user can set fire by choosing an area on the 2D map and by clicking the "Fire Mode" button. Setting fire on more than one place is allowed. The user can also change wind directions and speeds by using the appropriate input boxes.

To put the 2D map in context, we overlay it onto the corresponding area in Google Maps, as shown in Figure 6. The overlay opacity can be changed by selecting a value between zero and one and confirmed by clicking the "Confirm Opacity" button. The user can then validate the data and visually determine if the 2D map matches the real world. The users can also remove and recover the overlay on Google Maps by using the "Remove the Overlay Image" and "Add the Overlay Image" buttons. The overlay is then updated as soon as the 2D map is modified.

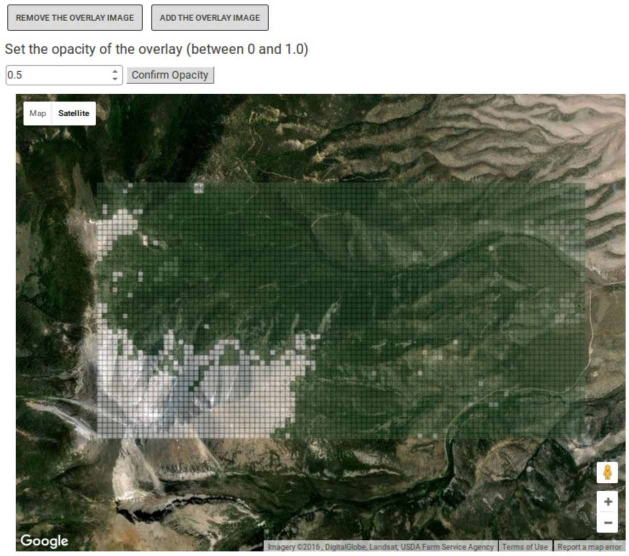

Figure 6. Overlay 2D Map on Google Map

D. *Vegetation and Wind Effects*

As the user changes vegetation and wind speed/direction, RWWSS shows the effects of the changes on fire propagation. Figure 7 highlights an area for which a user changed the trees to a mixture of vegetation. In the red circle, the left and right parts are grasses, the top part is shrubs, and the bottom part is bare ground. The yellow cells are set on fire, and then the spread of the fire is shown, as presented in Figure **8**. Red indicates the active fire, and white indicates areas where the fire has burned out. It is clear that the fire spread is slowed down by shrubs and quarantined by bare ground.

Figure 7. Modify Vegetation Type and Start Fire

Table I. Comparison of Methods and Applications

Name	Real Time	Users Need to Install Dependencies	Support for Multi-platforms	Open Source & Free	For General Use
V-FIRE [23]	Yes	Yes	Possible Yes	Yes	Yes
Smith's Speed-up [4][30]	Yes	Yes	Possible Yes	Yes	Yes
AEGIS [22]	No	Yes	Yes	Yes	No
RWWSS	Yes	No	Yes	Yes	Yes

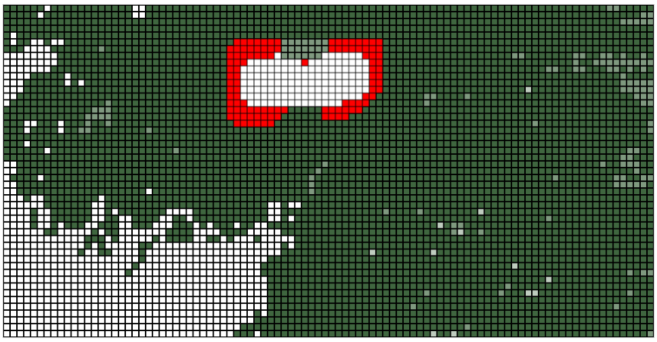

Figure 8**. Display Vegetation Type Effects on Fire**

If the user sets the wind to blow to the northeast, the fire is spread as shown in Figure **9**. The right angle in the south-west corner of the fire spread area is caused by the 3 x 3 grid used in the burn distances model (introduced in Section III.B). The wind speed can also affect the vegetation burning time. Naturally, a strong wind can accelerate fire burning.

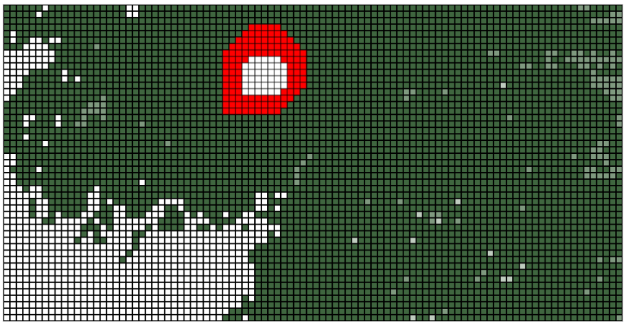

Figure 9**. Visualize Wind Direction Effects on Fire**

V. RELATED APPLICATIONS

This section introduces several similar wildfire simulation applications and tools. Most of tools are not web-based applications, which means users need to install dependencies.

Harris et al. [22] created V-FIRE, a 3D fire simulation and visualization software. The software has a powerful animation component and an intuitive control menu. V-FIRE was improved by Roger Hoang et al. in [23] and [24]. This improvement used Rothermel's fire model [14], leveraged GPU computing power, and displayed visualization results in a six-sided virtual reality environment. V-FIRE is suitable for both education and research.

In her master's thesis [4] and a conference paper [30], Jessie Smith introduced a new method using GPU parallel programming to speed up Rothermel's fire model. Her method enables real-time wildfire simulation, taking only about 0.8 second to run the fire model. The GPU parallel programming could be used in a future implementation of RWWSS to increase its speed.

Kalabokidis et al. [22] developed AEGIS, a system using open source Web-GIS [26] for mapping services and geo-processing. Their research focuses on Greece and we believe it is possible that they can apply their methods to other places as well. The system is powerful and contains many visualization methods suitable for fire simulation. Also, the system works on multi-platforms, but not on all platforms.

Table I presents a comparison of RWWSS and the three aforementioned systems.

VI. CONCLUSION AND FUTURE WORK

This paper has introduced a simplified fire simulation model that is suited for educational purposes; it also presented the implemented system designed to run the model in real time.

The main advantages of RWWSS are: (i) the system is cross-platform and does not require installation—as such it is accessible via any browser running on any device; (ii) it can be used for any location for which valid datasets are available; (iii) the user can save the values changed (vegetation types and wind data) in the database for future studies; and (iv) the system runs in real time at adjustable speeds. "Real time" means our system can respond fast enough that the users cannot tell the simulation time consumption while the system renders the results.

RWWSS was created as an educational tool and therefore at this time is not accurate enough for research purposes. However, the authors are looking into improving the model without losing its valuable real-time characteristics. During the testing it was noticed that RWWSS could be slow if there are too many active cells. Parallel programming (e.g., parallel.js [1]) can be used to improve the speed of the software.

Our code, consisting of about 2,000 lines, is shared on GitHub [6].

The model presented in this paper is a simplified fire propagation model, affected by the major factors of ground slope, wind speed, wind direction, and vegetation type. The model could be further improved with quantitative assessment of real-time fire propagation and as such could be used in forest management. This could be done by coupling it with theoretical or physical-based models, while keeping the RWWSS model in its relatively simple form.

The grid digitalization of the Lehman Creek watershed and its classification of vegetation type accommodates and is consistent with the requirements of the hydrologic model PRMS [21], [29], which simulates hydrologic processes such as streamflow, with parameters that represent of physical geographical conditions (e.g. land cover, land use, and soil type) and input meteorological conditions (precipitation, maximum temperature, and minimum temperature). Thus, the impact of land cover change caused by wildfires on streamflow could be quantitatively assessed. Water resource availability could be evaluated to provide water resource managers increased guidance for regional social-economic developments in agriculture, industry, and municipality.

We are now working on obtaining model inputs from geological websites, such as USGS, and then converting the data into JSON format. This will enable users to do fire simulations in different locations as long as the chosen geological websites have the corresponding input data.

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