A small network model to predict wildland fire dynamics at laboratory scale

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Introduction

Every year, wildland fires still destroy millions of hectares of vegetation or forest. In some cases, they are a natural part of the ecosystem affecting the vegetation cover and boosting the growth of some species. However, in many cases, these fires are difficult to control and may lead to the destruction of private or public properties. Sometimes the fire fronts reach the urban interface destroying homes and causing deaths. Recently, the Camp Fire was considered as the deadliest and most destructive wildfire in the California history.

For the last two decades, the scientific community of fire safety science worked on the development of physical models to understand the flame dynamics of the wildland fire. These models aimed at providing useful information to estimate the risk factors or to help the decision-making of firefighters during a fire front propagation scenario or to help fire investigations after a disaster.

Models developed to represent the wildland fire spreading are divided into three categories: mathematical/physical models, semi-empirical models, and empirical models. Pastor *et al.* (2003) and Sullivan (2009) propose the more recent surveys of these fire propagation models.

Among the mathematical models, the cellular automata model seems to be a promising solution for the wildland fire propagation because of its simplicity of implementation and the low-computational cost. This kind of approach has been successfully applied over a broad range of physical problems, such as the vegetation competition dynamics by Matsinos and Troumbis (2002) or the fire evacuation of a building by Yang *et al*. (2002).

Watts and Strogatz (1998) extended the class of cellular automata by introducing the concept of a small world network. This sub-class of models add the effect of long-range connections. For wildland fire spreading, Porterie *et al.* (2007), in particular, demonstrated the efficiency of this kind of model.

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The present work proposes an original approach to represent the fire front propagation by a Small World Network. This new model uses experimental data instead of physical laws to calibrate its parameters.

Small world network model to fire spread modelling

For wildland fires, the small world network model consists in dividing the fuel bed into elementary cells. A discrete state defined from 1 to 4 characterizes the cell. State #1 stands for raw combustible material, state #2 for thermal degradation of the material, state #3 for material in fire and state #4 for burnt material. A non-dimensional parameter named τ_j determines the state of the *j*th cell. If τ_j is equal to 0 then the state remains at #1. At the vicinity of the fire front, τ_j rises and the cell state becomes #2. When τ_j reaches the threshold value τ_c, the cell evolves to state #3. The cell stays in state #3 as long as τ_j is smaller than τ_d. Beyond this last threshold, the state is at #4. The *j*th cell, at $\boldsymbol{x}_j$, follows the conservation equation given by,

$$\frac{d\tau_j}{dt} = \int_{S\in\{Fire\ front\}} H(\|\boldsymbol{x}_j - \boldsymbol{x}\|)\mathrm{d}S$$

where d*S* is a part of the fire front located at the position x and H a distribution function representing the heat transfer by convection and radiation of the elementary fire front d*S* on the cell j.

For the present work, we have only considered the case with no wind and no slope. The distribution function *H* is then isotropic and decreases with the distance *r* (as described in Fig. 1). We choose to represent this function as a sum of local piecewise linear hat functions. Fig. 1 shows an example of a hat function. This feature represents the originality of this work. The *H* function is then represented by,

$$H(r) = \sum_{i=1}^{N} \alpha_i \phi_i(r)$$

Where *N* is the number of hat functions used to represent *H* and *r* represents the distance between two cell centers.

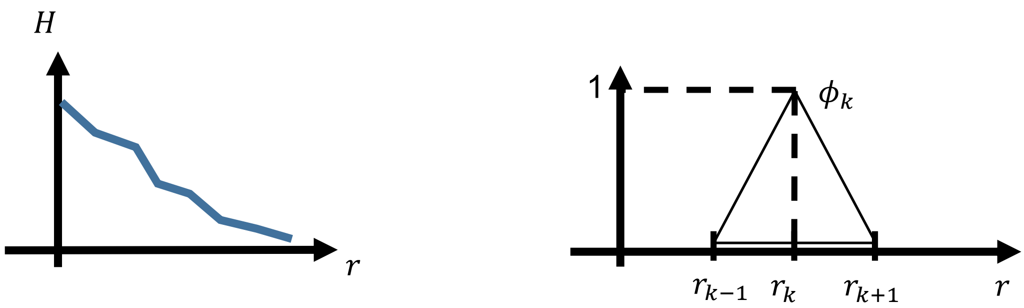

Fig 1. Representation of the distribution function H (left) and Hat function (right)

The propagation model relies on *N*+2 parameters. They have to be calibrated by experimental data since these parameters cannot be identified by physical laws or estimated by any experimental measurement.
We choose to calibrate these parameters from fire propagations performed at a laboratory scale using Excelsior as fuel. A database gathers all the achieved experiments, included the rate of spread and the fire front width as a function of the fuel bed dimensions and the vegetation load. Fig. 2 gives an example of a propagation.

Fig 2. Experimental study of the rate of spread and the fire front width

Therefore, a Particle Swarm Optimization (PSO) algorithm identifies the N+2 parameters involved in the Small World Network. Then, the model is tested in a configuration where the fuel bed contains one or several fuel-breaks to evaluate the efficiency of the results predicted by the proposed model.
The oral presentation will detail the experimental setup and the database used by the PSO algorithm. The application used for testing the new fire propagation model will be presented and discussed.

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