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Interactive fire spread simulations with extinguishment support for Virtual Reality training tools

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ABSTRACT

Virtual Reality training for fire fighters and managers has two main advantages. On one hand, it supports the simulation of complex scenarios like big cities, where a fire cannot be simulated in the real world. On the other hand, fire fighting VR simulators allow trainees to experience situations as similar as possible to real fire, reducing the probability of accidents when they are practising exercises with real fire.

The success of the Virtual Reality training tools also depends on how close to reality the simulation process is. This work provides fire spread algorithms for forest and urban environments, which can be used at interactive rates. Due to the interactive nature of the algorithms, the users are able to fight the fire by throwing extinguishing agents.

Although the algorithms assume many simplifications of the problem, their behaviour is satisfactory. This is due to the efficient management of the cell states in a 3 m × 3 m cell grid. Also the variables that have more influence on fire propagation constitute the core of the algorithms. The overall system deals with user extinguishment actions, natural and artificial firebreaks, variable wind conditions (even at a cell level) and non-contiguous fire propagation (embers and spotting fires). The unified forest/urban model leads to an object oriented architecture which supports the fire propagation algorithms. This also allows the system to compute efficiently mixed forest–urban environments.

1. Introduction

The impact of forest and urban fires on the society is high. Although the consequences might vary from an event to another, the impact normally resides on the potential economical losses due to the fire, the damage to the environment in short and long terms, the damages to urban structures and the eventual human casualties.

Despite the preventive measures that avoid the development or limit the impact of the forest and urban fires, such fire events will happen eventually. At that point, the fire fighters will be called into the field to limit the devastation of the fires and to protect the people.

The fire fighters and managers must be fully trained professionals to do their job with the best possible outcome and to reduce unnecessary risks. The training is composed of theoretical content and some supervised practical exercises with controlled real fire. Essentially, these practical exercises are oriented to teach the trainees how to wear the equipment in warm environments under stress situations. Due to security reasons, the practical exercises are constrained to just a few physical simulators with induced fuel gas fire. In these situations, the fire does not behave realistically, so the fire behaviour knowledge is left at a theoretical level till the first time the trainees go to the field in a real fire event.

Virtual Reality techniques have been used as a key technology in driving simulators, machinery handling simulators, etc. The application of VR techniques to the fire fighting scenario helps in the training process by increasing the possible scenarios and modifying the conditions of the training sessions. Furthermore, the absence of real fire increases dramatically the security and therefore, the safety measures can be reduced significantly.

From the point of view of such a VR simulation system for training fire fighters, there is a main algorithmic element: the simulation of how the fire spreads as simulation time advances. If a very unrealistic behaviour of the fire is shown to the trainees, the *immersiveness* and the credibility of the simulation will be reduced dramatically and the training objectives would be compromised. The introduction of complex mathematical models to simulate the fire behaviour makes difficult a realtime implementation, which is a mandatory requirement in VR setups. Thus, to meet the interactivity requirements, a simplification of the algorithms involved in the fire spread simulation is needed.

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The targeted scenarios for the VR training tool are the forest and urban areas. The different types of vegetation and buildings modify how the fire spreads. Additionally, the apparition of spotting fires is common in both forest and urban areas, being one of the main fire spreading mechanisms.

The suppression of the fire is supported in two ways: by self-extinguishment (fuel combustion) and by the action of the fire fighters. The interactive nature of the VR simulation is required for the trainees, since they interact with the fire behaviour by throwing an extinguishing agent.

In this work, we present fire spread algorithms that can be used in real time within interactive virtual simulations. The algorithms are intended to produce approximated but fast results that could be used in the training of fire fighters and managers.

In the next section, some of the related work for fire spread will be reviewed. Next, the proposed algorithms for the forest and urban environments will be described, followed by the validation. Finally, the conclusions and future work will be addressed.

2. Related work

There are two major models of fire simulation: empirical models and physical models.

The empirical models follow the experiences gathered with real fires. These models use statistical relationships found between the fire evolution and different parameters tested on the field [1]. Within this group, we can mention FARSITE [2], which uses the Huygens principle of wave propagation.

The physical models use convection and heat transfer mechanisms and/or Computational Fluid Dynamics methods. The main mathematical tools they use are partial differential equations and reaction diffusion systems. Fire Dynamic Simulator (FDS, National Institute of Standards and Technology - NIST) or FIRETEC [3] follow this approach.

Seron et al. [4] and Ferragut et al. [5,6] provided physical models with some empiric variables, which make their solutions hybrid. The advantage of these models is their accuracy in the fire prediction. Morvan et al. [7] used them to study the interactions between fire fronts, but the computational effort is very high. The mathematical models are too complex and computers can only provide approximate solutions [8]. Another consequence is that increasing the spatial resolution causes too long computational times.

Unlike the two previous models, other research works have taken a different direction from the complex mathematical models. Their objective is to reduce computation time and to implement a real time simulation. Achtemeier [9] presented the *Rabbit Model*, a collection of basic rules of fire evolution, which are implemented as autonomous agents (the rabbits). The scope of the *Rabbit Model* is limited to the evolution of wildland fires.

Lee et al. [10] proposed a physical model for urban fires. The authors use equations to describe the heat transfer between buildings (radiation and convection), the temperature modification, and flame shape (direction and length) coming out through the windows.

Weise and Biging [11] proposed a physics based model to simulate the fire spread in non-homogeneous cities with high resolution. Cheng and Hadjisophocleous [12] modelled the fire spread in buildings taking into account the connectivity between rooms and stories. Stern-Gottfried and Rein [13] introduced the *travelling fires* to support the fire dynamics in buildings.

Iwami et al. [14] introduced a very descriptive physical model for urban fires, providing different stages for each considered building type. Ohgai et al. [15] presented a physical model using cellular automata over a grid of 9 m^2.

The algorithms proposed in this work present an urban and forest fire spreading simulation, whose main characteristics are:

- In forest areas, the fire evolution is based on the terrain topology, material and wind conditions. In urban areas, in order to obtain more accurate results, the different building characteristics are used.
- The fire may cross rivers, firebreaks or other barriers by throwing firebrands, producing spotting fires on the other side of the barrier. This mechanism is also used to spread the fire between buildings. In a similar way, urban fire can spread to forest areas and vice versa.
- Very low complexity, allowing real time simulation even with standard computing power.
- Fire suppression support. Throwing the extinguishing agent affects how the fire spreads.

Sections 3 and 4 describe the proposed algorithms. Following sections present results and performance analyses.

3. Fire spread algorithms for wildland areas

The fire fighting simulator has to get rapid results for the fire spread process in forest and urban areas. The system (see Fig. 1) must provide a fast response to support the user interactions and dynamic changes of the wind conditions.

The main objective of this work is to provide novel algorithms to reduce the algorithmic complexity and the processing time. They follow and extend the works of Achtemeier [9], Iwami et al. [14] and some of our previous work [16]. The most relevant variables are taken into account: wind and slope [11,17].

3.1. Field definition

The simulation algorithms utilise a regularly divided field (grid). Each cell of the field has its geometrical information (position and altitude) and its state. Fig. 2 shows in a graphical way the terminology used to define the relationships of the cells in the field. For a given cell, we define its neighbours as the 8 closer cells. The surroundings of a cell include a set of cells enclosed in an elliptical or circular region.

Each cell has a type, which determines the nature of the cell (dry grass, tall trees, water bodies, roads, etc.) and its behaviour. Also, each cell has variables which are updated by the algorithms in each simulation step: *State*, *FirePower*, *MaxFirePower*, *Fuel*, *AmountAgent*, etc. These variables will be defined in the algorithms.

3.2. Cell states

All the cells in the field have an internal state which describes the state of the fire that exists in such cell. The different states are `Safe`, `Activated`, `Burnt`, `Survive`,

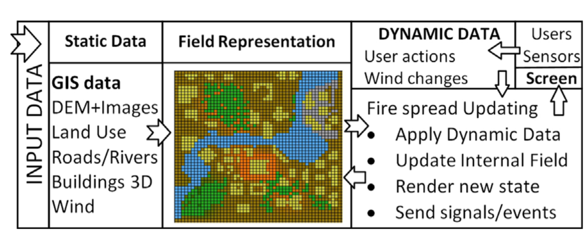

Fig. 1. The simulation architecture builds the scenario from static information. During the simulation, the fire evolves according to the user actions, the fire spread algorithms and the wind changes [16].