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An integrated approach for tactical monitoring and data-driven spread forecasting of wildfires

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ABSTRACT

In recent times there have been increasing efforts to integrate technology into wildfire management, especially in the fields of tactical monitoring and simulation. On the one hand, thermal infrared imaging (TIR) systems have been installed aboard surveillance aircraft including unmanned systems (UAS). On the other, there exists a variety of models and simulators able to forecast the fire spread. However, both fields currently present significant limitations. While relevant information is still extracted manually from aerial thermal imagery and is most times merely qualitative, simulators' accuracy on fire spread prediction has proved insufficient. To solve these issues, this article presents a twofold methodology to couple meaningful automated wildfire monitoring with accurate fire spread forecasting. The main goals are to, firstly, automatically process aerial TIR imagery so that valuable information can be produced in real time during the event and, secondly, use this information to adjust a Rothermel-based simulator in order to improve its accuracy on-line. The fire perimeter location is tracked automatically through an unsupervised edge detector. Afterwards, an assimilation module uses the remotely sensed data to optimise the simulator's fuel and wind parameters, which are assumed to remain constant for a certain period of time. Subsequently, the optimum parameters' values are used to issue a fire evolution forecast. All outputs are projected onto the corresponding Digital Terrain Model (DTM) and integrated into a Geographic Information System (GIS) for visualization. The global system was validated using two large-scale experiments. If these algorithms can be applied to a sufficiently rich and varied set of experimental data and further developed to cope with more complex scenarios, they could eventually be incorporated into a fire management decision support system.

1. Introduction

Forest fires have been gaining attention in recent times. Partially favoured by global warming, the annual number of fires and the subsequent burned area have been increasing during the past decades [1,2] in the European Mediterranean region, and have been predicted to continue rising in the near future [3,4]. Furthermore, phenomena such as eruptive fires or fire whirls appear more and more frequently and worsen the fact that wildfire dynamics are not yet completely well understood [5,6]. In extreme cases, a significant amount of casualties occur as a consequence of unforeseen fire evolution, e.g. in Australia's Black Saturday in 2009 (173 victims) or in Yarnell Hill, Arizona, US, in 2013 (19 victims). Even when there are no casualties, important economic losses are suffered and large budgets spent [7].

Motivated by these reasons, there have been important technological advancements related to fire management. Remote Sensing systems have been developed and installed aboard a variety of platforms [8]. Spaceborne imagery, although currently used for tasks such the estimation of surface fuel loading, hot-spot detection and remote measurement of burned areas, presents too coarse spatial and temporal resolutions to be suitable for active fire surveillance. On the contrary, airborne thermal infrared imagers proved very promising and are currently operative in several cases [9–12]. However, fire properties are not yet extracted automatically. So far, images are in general analysed qualitatively and fire front locations, when computed, are delineated manually [13–16]. On the other hand, there exist a number of mathematical, physical and semi-empirical models for wildfire propagation simulation [17–20]. However, no solution has been found suitable for implementation during the incident management as part of a decision support system (DDS). High-accuracy simulators based on computational fluid dynamics (CFD) [21–24] require enormous computational resources and their use is thus restricted to research studies and reduced simulation domains [25], whereas models which could be run in an operational time-constrained framework [26,27] have proved unable to successfully predict the observed rates of spread (ROS) [28]. Moreover, a problem common to both types of simulators is the

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Nomenclature

A	Area within the fire perimeter
c	Set of Canny's hysteresis thresholds candidates
M_f	Fuel moisture content (%)
M_x	Fuel moisture of extinction (%)
ROS	Rate of Spread (m/min)
SAV	Fuel surface area-to-volume ratio (m^{-1})
U	Wind speed at mid-flame height (m/s)
W_o	Fuel oven-dry fuel loading (kg/m^2)

Greek

α	Terrain aspect (rad)
δ	Fuel depth (m)
φ	Terrain slope (rad)
σ	Gaussian filter standard deviation
θ	Wind direction at mid-flame height (rad)

Superscripts

ob	observed
m	modelled

scarcity of precise data available to initialise them [6]. Data assimilation was adopted as an alternative to make use of the advantageous speed of simpler methods while improving their accuracy [29–36]. Its rationale is based on the assimilation of the observed fire perimeter location at different times (also called isochrones) and the subsequent optimisation of fuel and weather parameters so that modelled fire evolution resembles the observed.

In this context, we developed an integrated system built upon

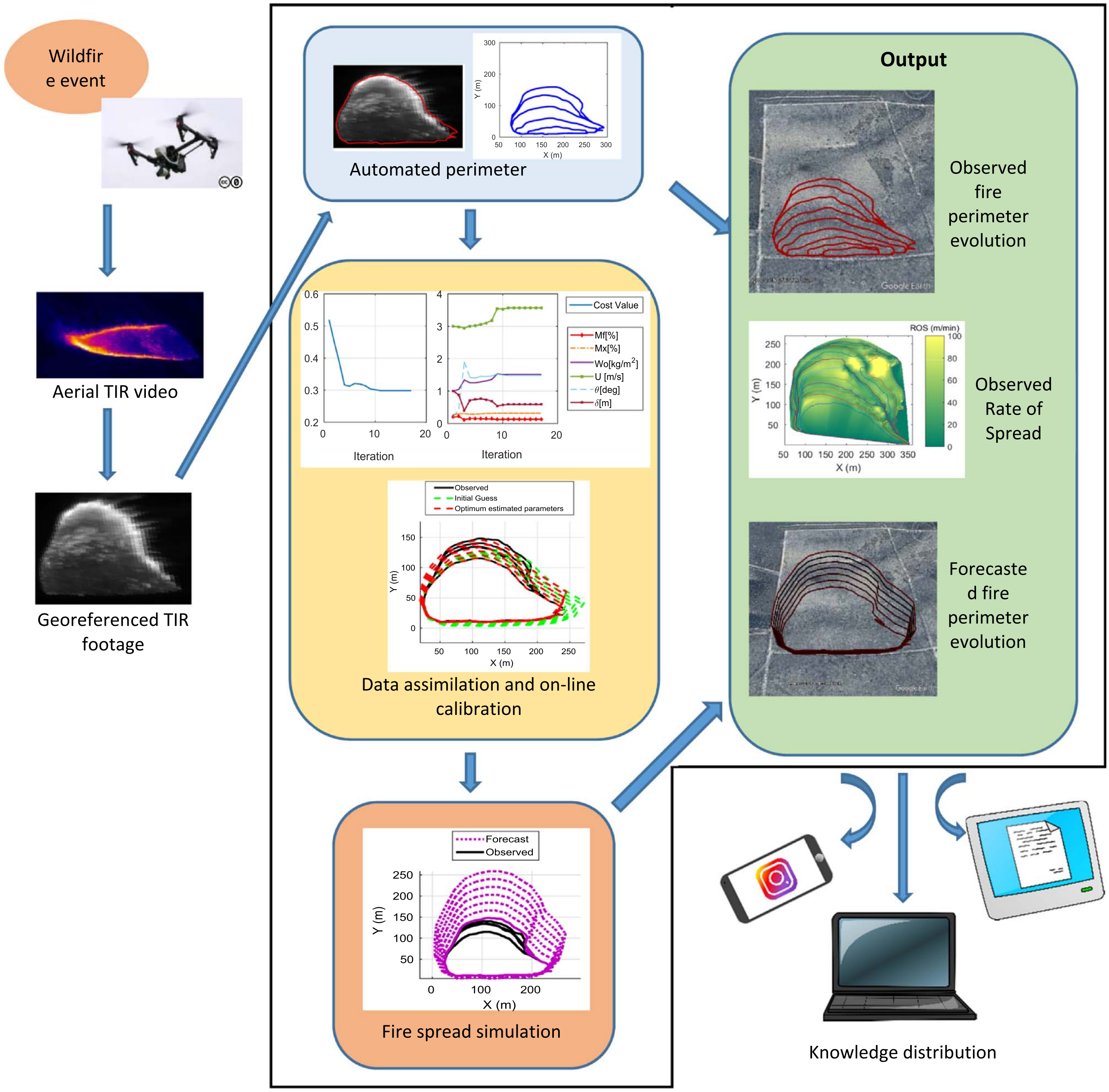

Fig. 1. Block diagram of the presented system. The tasks inside the box fall within the scope of this article.