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# Reasoning on multi-sensor geographic smoke spread data for fire development and risk analysis

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ABSTRACT

This paper presents the general architecture of a multi-sensor geographic information system which allows for the effective use of sensor data and geographic information in fire incident management and fire development analysis. The proposed platform allows the generation of real-time heatmaps that show the space–time distribution of fire/smoke risk levels across an area of concern based on multi-view sensing. Such levels are there to assist the decision makers in taking actions and aims at facilitating quick fire emergency response. Results of several real fire experiments in a large-scale road tunnel and in a multi-compartment set-up show the feasibility of the approach. Furthermore, by temporal analysis of the within- and between-variance of the sensor estimations, an indication on the accuracy/certainty of the measurements at each moment in time can be given. In this way, problems that arise in one sensor can be compensated by the other surrounding sensors. Finally, user experience studies have shown that the platform improves the current visualization of fire characteristics.

## 1. Introduction

Geographic data is stored and used almost daily in many organizations, i.e., the combination of communication technology and geo-information is in growing expansion and changing in nature [1,2]. In the context of disaster management, location identification is becoming increasingly effective, having a major role in the decision making process [3–5]. However, the real utilization of geo-information, such as road/building maps and real-time traffic data, and its combination with geotagged fire incident data is still limited in the analysis of fire emergency situations [6]. Geographic reasoning on fire events from heterogeneous multi-sensor observations, i.e., the research topic of this paper, will help the fire crew in their decision-making process [7,8]. Our fast on-site collaborative data collection and dynamic incident map creation on which space–time visual analysis can be performed will facilitate future fire operations.

The location, the size and the thickness of smoke can change the action plan as to how to fight the fire. As such, reading smoke is essential for early warning and prediction of the fire behavior [9–11]. By observing the spreading characteristics and the thickness of smoke, firefighters can have a better understanding of the conditions that they will face. The proposed fire geographic information system 'fireGIS' facilitates the smoke reading and automatically measures the fire characteristics and visualizes them on a spatio-temporal map of the environment. This spatio-temporal map is useful for evaluation of real fire experiments, e.g., to compare the impact of sprinklers and smoke evacuation systems, as is done in our experiments.

FireGIS builds further on the multi-modal/multi-sensor fire detection work that has been performed during the past years [12–14] and extends it with the spatio-temporal mapping of the sensor data into real-time heatmaps that show the space–time distribution of fire risk levels. There are three major steps involved in the fireGIS process: (1) the collection of low-cost (i.e., computationally efficient) multi-sensor data for the fire risk assessment; (2) the fire maps creation; and (3) the spatio-temporal fire risk analysis. Within this paper, Section 2 will discuss each of these steps in more detail and illustrate their application by means of several real fire experiments that are described in Section 3. In these experiments, different cameras were used to monitor the visibility-based smoke features. The visibility measurement is explained in more detail in Section 4. Temporal analysis of the within- and between-variance of the sensors' visibility estimations are used to give an indication on the accuracy/certainty of the measurements at each moment in time. In this way, problems that arise in one sensor can be compensated by the other surrounding sensors. This is further explained in Section 5. Furthermore, Section 6 presents the fire map generation and Section 7 discusses the evaluation and verification of the platform. This is done by a subjective analysis of the movies with respect to the visibility and an objective comparison to the temperature

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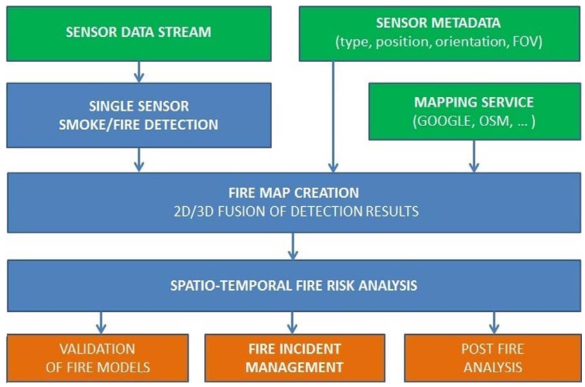



**Fig. 1.** Generic fireGIS architecture for spatio-temporal fire risk analysis.

profiles of a set of thermocouple trees. Finally it is important to mention that the fireGIS system is novel, i.e., next step, in the direction of fire spreading forecasting [15,16]. Related to this, Section 8 provides some further research directions for future forecasting research.

## 2. General fireGIS architecture

The general architecture of the fireGIS platform is shown in Fig. 1. In order to start up the fireGIS analysis, the platform needs to get meta data input about the sensors and the environment which needs to be monitored. For each of the available sensors, a link to the sensor data stream and the location information, i.e., position, orientation and field of view (FOV), needs to be registered in the fireGIS platform. In our tunnel experiments, for example, this information was provided by the Agency for Roads and Traffic (AWV) and the Flemish Tunnel and Control Center (VTC). In Fig. 2, an overview is given about the data which was provided by both agencies. It is important to remark that, in its current form, the data is difficult to import in the fireGIS architecture directly and some pre-processing is needed. In the future, better guidelines should be developed describing how to deliver this kind of data in an efficient way. Finally, the user needs to choose on which mapping service, e.g., Google Maps or OpenStreetMap (OSM), the spatio-temporal fireGIS detection results, i.e., the output of our platform, need to be shown. It is also possible to map the information on an existing floor plan of the environment, as shown in Fig. 3. This experiment was done in the context of multi-compartment fire tests at WarringtonFireGent (in cooperation with VIPA).

In the next step, i.e., after all meta data information is provided, the low-cost smoke analyzing algorithms will start analyzing the visual data streams. This process is further described in Section 4. In this paper, we mainly discuss the use of video data but the generic character of the framework also allows other sensor types to be included. In Section 7, for example, we describe the incorporation of temperature data/profiles derived from a set of thermocouple trees. Subsequently, the sensor detection results are projected to a 2D or 3D map of the environment using the location information of the sensors, as shown in Fig. 2. In order to give an indication of the fire risk, different color codes ranging from green to red are used, corresponding to the detected smoke/visibility at each monitored point/region. For the presented fire experiments, mapping is done to a 2D representation of the environment. However, 3D mappings are also possible and have been investigated in [17].

Finally, by analyzing the generated fire risk maps over time, a spatio-temporal analysis can be performed on the fire spreading. This can be very useful real-time information for fire incident management, but can also be used for post-fire analysis. In future work the system will also assist the validation and improvement of existing fire models.

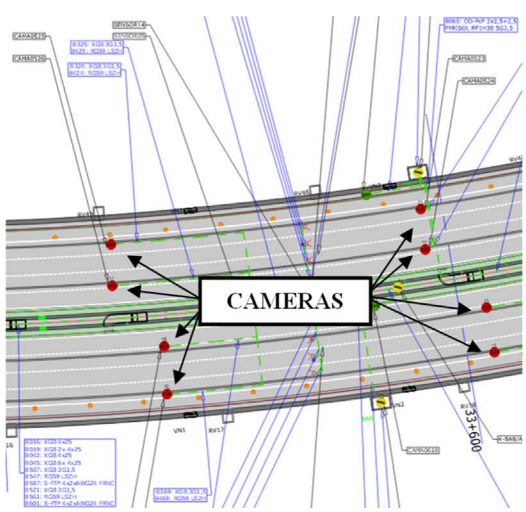
It is important to remark that it is not the intention of this paper to propose a new fire or smoke detection algorithm. The fireGIS platform is more like a system methodology in which the fire/smoke detection mechanism is a black box independent of the used sensor type, i.e., the detection itself can easily be replaced and extended with other state-of-the-art detectors available in the literature [18,19].

## 3. Real fire experiments

Before going more into detail on the video smoke analyzer and the spatio-temporal fire risk analysis, this section provides additional information about our real fire experiments. There exist some other examples of such experiments, like Tisova [20], Dalmarnock [21] and Rabot [22]. However, such experiments are limited in number due to the high costs involved in organizing those. Numerical simulations, on the other hand, are relatively cheap, but they suffer from computational complexity. Overall we need to use each opportunity of real fire experiments to further optimize the simulations and use them to get more knowledge in fire behavior.

### 3.1. Multi-compartment fire test

A first large-scale test for evaluation of the platform has been performed in association with WFRGent and VIPA in September 2015. The outcome of these tests are used to investigate the impact of




| Filename | Link | Orientation | Position |
|---|---|---|---|
| CAMA0592.mov | link | SO | 4 |
| CAMA0624p.mov | link | PTZ | 3.5 |
| CAMA0590.mov | link | SA | 3 |
| | | | 2.5 |
| CAMA0588.mov | link | SA | 2 |
| CAMA0586.mov | link | SA | 1 |
| CAMA0622p.mov | link | PTZ | 0.5 |
| | | | 0 |
| CAMA0582.mov | link | SO | -1 |
| | | | -1.5 |
| CAMA0580.mov | link | SO | -2 |
| CAMA0578.mov | link | SO | -3 |
| CAMA0620p.mov | link | PTZ | -3.5 |
| CAMA0576.mov | link | SO | -4 |

**Fig. 2.** Sensor and environment input provided by the Agency for Roads and Traffic (AWV) and the Flemish Tunnel and Control Center (VTC) – Road map with sensor locations (left) and links to sensor data streams and additional positioning/orientation information (right). (For interpretation of the references to color in this figure, the reader is referred to the web version of this paper.)