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Fireground location understanding by semantic linking of visual objects and building information models

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ABSTRACT

This paper presents an outline for improved localization and situational awareness in fire emergency situations based on semantic technology and computer vision techniques. The novelty of our methodology lies in the semantic linking of video object recognition results from visual and thermal cameras with Building Information Models (BIM). The current limitations and possibilities of certain building information streams in the context of fire safety or fire incident management are addressed in this paper. Furthermore, our data management tools match higher-level semantic metadata descriptors of BIM and deep-learning based visual object recognition and classification networks. Based on these matches, estimations can be generated of camera, objects and event positions in the BIM model, transforming it from a static source of information into a rich, dynamic data provider. Previous work has already investigated the possibilities to link BIM and low-cost point sensors for fireground understanding, but these approaches did not take into account the benefits of video analysis and recent developments in semantics and feature learning research. Finally, the strengths of the proposed approach compared to the state-of-the-art is its (semi-)automatic workflow, generic and modular setup and multi-modal strategy, which allows to automatically create situational awareness, to improve localization and to facilitate the overall fire understanding.

1. Introduction

On the one hand, when a fire fighter crew arrives at a fire scene the set-up is unknown, although the commander in chief needs to take fast and appropriate decisions. The location of the fire source, the amount and the position of the victims, the structure and the lay-out of the building, and the health and the location of the firefighters are mostly unknown factors that could influence the firefighting strategy. On the other hand, there is more and more geographic data stored and used almost daily in many organizations. However, the real utilization of geo-information, such as building maps and real-time sensing data is still limited in the analysis of fire emergency situations. Furthermore, there is currently no system that helps in understanding and linking the actual state of the building and the fire behavior during a fire.

The goal of this is paper is to focus on the state-of-the-art in building information models, location understanding for fire incident management and situational awareness. Secondly, an outline is provided to combine the different sources of information involved in fireground analysis. For example, by combining the information of the building model with the results of state-of-the-art computer vision techniques applied on video sensors, an improved understanding of the fireground scene can be achieved. Furthermore, object detection, scene classification and room layout estimation will help in localizing fire fighters, which is a difficult task due to the reduced visibility and dynamic characteristics of the fire environment. The information gained by the proposed architecture could even be used to verify or to update the building information models, which increases their practical applicability. Fig. 1 gives a global overview of the proposed approach and shows the links between BIM, visual analysis and the localization problem. Finally, it is important to remark that the proposed framework is work in progress and subject to change over time.

The remainder of this paper is organized as follows. Section 2 presents the global framework for combining low-cost sensing, building information and location understanding. The details of each individual building block are given in the next sections. Section 3 gives a literature overview of building information modeling in the context of fire safety design and fire incident management. Subsequently, Section 4 proposes the possibilities of localization understanding with low-cost video sensors during a fire. Next, Section 5 focuses on the semantic location understanding for location recognition and Section 6 describes the linking process and evaluation methods. Finally, Section 7 lists

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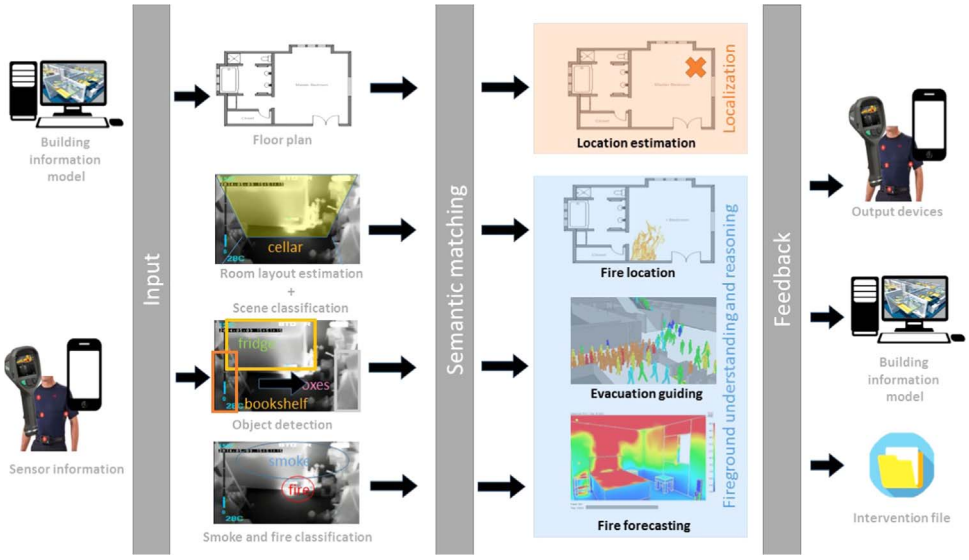

Fig. 1. Global overview of the proposed system for semantic linking of video object recognition results with building information models.

some conclusions and points out directions for future work.

2. Fireground understanding and visualization

The two main goals for combining building information models with real-time sensing data are to improve localization and to facilitate fireground understanding and reasoning. The global framework, shown in Fig. 1, links the following components/modules of both modalities in order to achieve both goals:

- For accurate localization, the **floorplan** generated from the **BIM** is combined with the **room layout estimation** from our low-cost video localization devices. By describing both data types in a semantic way, semantic similarity between both annotations can be used to estimate the location on the floorplan the sensor is focusing on. Furthermore, additional semantic information of our **scene classification** module can be used to further improve the localization accuracy. However, currently this module only works on visual images. Research is going on to adapt this technique so that is also applicable on thermal camera images. Both modules improve the situational awareness/localization and facilitate evacuation guiding.
- **Semantic annotations** of the **object detection module** and our **smoke/fire classification algorithms**, on their turn, will continuously update the BIM with real-time information of the fireground. In this way, a detailed spatio-temporal description of the fire evolution can be generated facilitating the overall fire understanding. In combination with the room layout estimation and the scene classification, the object detection module can even be used to perform BIM updates.
- **Real-time localized sensing data** of the environment (i.e., pressure, smoke layer interface height, smoke and fire location) can be coupled to a **fire forecasting mechanism**. In combination with BIM, the forecasting mechanism could update the evacuation guiding and generate risk warnings for firefighters.
- Finally, our detection results are sent back as feedback to our sensing devices and the BIM model. Furthermore, a dynamic, self-updating intervention file could be generated with our real-time detection results. This logging data can, for example, be useful in post-intervention analysis.

Although the building information model is a rich source of information it is important to remark that currently, not many buildings have a decent model. This limits its applicability in the proposed architecture. However, by showing the possibilities of BIM in systems like ours, we believe that its availability and accuracy will increase, making it a rich source of information for a wide variety of applications.

Besides the technical issues, which are the focus of this paper, it is also important to address the factors that will influence the efficiency and the effectivity of the proposed application. Sarshar et al. [1] give some valuable remarks on the usability of smartphone apps in emergencies. In addition, visualization aspects needs also to be evaluated and investigated in our context. There is a large amount of sensing data, building data, and forecasting results that need to be structured and communicated in the final application. User experience studies with the different end users/stakeholders are necessary to adapt the framework's output to their specific needs. The work of Nunavath et al. [2], which analyzes emergency communication during interventions, is already a preliminary step into this direction and can be used as a starting base, but further user experience research is needed. Furthermore, the work of Vandecasteele et al. [3] indicated that a decent visualization can give more insight in the large amount of sensing data during real fire experiments. Recently we also launched a national questionnaire survey for firefighter representatives and leaders focusing on data needs and visualization during an intervention. The discussion of the results and gained insight are out of scope of this technology-focused research paper, but will be part of our future publications.

Within the next sections, we give a thorough explanation of each of the building blocks of our framework. The most important and novel step, i.e. the semantic matching of the sensor data with the building model, is discussed in Section 6 and performs reasoning on each of the other building blocks' output.

3. BIM: building information model

BIM is a tool to manage accurate building information over its whole life cycle [4]. BIM represents the building as models made of collections of building components such as walls, windows, doors and their relationship and properties. Initially it was only intended to support the design and construction processes, but currently there are numerous applications in different fields (e.g. facility management, fire safety engineering, climate control). Furthermore, due to the international Industry Foundation Class (IFC) standard it is now possible to share and store information of other software vendors and to transform the BIM data into semantic understandable data such as XML and