Smoke behaviour analysis with multi-view smoke spread data

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SMOKE BEHAVIOUR ANALYSIS WITH MULTI-VIEW SMOKE SPREAD DATA

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ABSTRACT

This paper presents a multi-sensor fire monitoring platform (called fireGIS) for smoke behaviour analysis. The platform allows the generation of real-time heatmaps and graphs that show the space-time distribution of smoke risk levels and smoke information across an area of concern. These outcomes are used to assist the decision makers in taking actions and aim at facilitating quick fire emergency response. Furthermore, the platform facilitates post fire risk analysis. By analysing the smoke maps of an entire building it is possible to perform a space-time analysis of the smoke direction, the speed, the smoke height and the visibility. The combination of these metrics makes it easier to get an understanding of the global smoke behaviour. The evaluation of the system is performed by subjective evaluation within real fire experiments. Finally, it is important to remark that the proposed methodology is suitable for different kinds of fire monitoring sensors. The focus within this paper, however, is put on multi-view sensing with cameras.

KEYWORDS: video fire analysis, multi view sensing, heat maps, smoke risk levels.

1. INTRODUCTION

Predicting the behaviour of fire in a compartment is very difficult due the large numbers of dynamic variables. Those variables are changing fast and getting a global overview of all of them is quasi impossible. However, there are fire and smoke indicators that could assist in the decision making process. Several fire fighter crews use the simple B-SAHF mnemonic (Hartin & Code) [1] for the 'smoke and fire reading' process. B-SAHF stands for building, smoke, air track, heat and flame. Currently the available information for the fire reading during an incident comes neither collected, nor processed in a systematic way. The fire fighters teams analyse independently their situation and this is based on local observations and personal knowledge. Finally the commander has to take actions based on the limited set of local observations and without knowledge of the entire fire ground. In case that the observations are misunderstood, problems can escalate very fast and fire losses are not uncommon (Fahy) [2].

Due to the fast evolution in hardware and software there are more and more sensor networks available (Othman & Shazali) [3] and (Lorincz et al) [4]. This can be exploited to improve the safety and the effectiveness of firefighting and fire understanding (Koo et al) [5]. There is also a tendency over the last years on video based smoke analysis (Çetin et al) [6]. However those mechanisms are mostly only suitable in detecting smoke. Within this paper we propose the fireGIS platform which is capable in collecting large quantities of sensing data, such as multi-view video data from cameras and this will go further than only detecting. With the proposed methodology it will be possible in the future to transform the firefighting from an information and experience based decision making to a data driven and science based decision making process (Grant et al) [7]. There exists already an active research in the data driven analysis of fire such as the work of (Pereira et al) [8] and (Miller & Ager) [9] for wildfire and (Beji et al) [10] for enclosure fires, but these works are currently not suitable for real-time compartment fire analysis.

Within this paper we will first discuss the global smoke reading process in order to facilitate the smoke behaviour analysis. Furthermore, Section 3 will give a detailed description of the generic architecture of our framework and the possibilities to expand it with additional sensors. Subsequently, Section 4 discusses the real fire experiments who were performed to illustrate and evaluate the proposed platform. Next, the visibility measurement and some existing methods to calculate the smoke height based on multi video data are explained in more detail in Section 5. Furthermore, in Section 6 we describe and evaluate the visualization of the characteristics for smoke behaviour analysis. Finally, Section 7 lists the conclusions and points out directions for future work.

2. SMOKE READING

Smoke gasses can be used to indicate the stage of development of the fire (Drysdale) [11]. A good understanding of the smoke spreading and behaviour is essential in generating an action plan as how to fight the fire. In the smoke reading process there are different attributes that can be used to get a general idea of the fire, such as the smoke colour, the location of the smoke, the optical density and the smoke height. Comparing smoke velocity and colour from different locations can help to locate the fire source. Fast moving, powerful thick black smoke for example is more closer to the fire, whereas slow light smoke is further away. The colour can also give information about the stage of development. However, it is important to remark that the colour is not a trustworthy method to calculate the amount of unburned fuel in the smoke. White smoke, for instance, could come from inert waterspout or could come from highly concentrated pyrolysis gasses which is highly flammable. A reduction in visibility could indicate a smoke full of soot or could come from a highly concentrated pyrolysis gas. The list of relationships of smoke attributes mentioned here is not limited and within this paper we propose a framework to facilitate the visualisation of these smoke features. The interpretation of the features is still some work for the commander and is currently not automated.

3. FRAMEWORK

The general architecture of the platform, shown in Figure 1, builds further on the multi-modal and multi-sensing fire detection work that has been performed during the last years (Verstockt) [12] and extends it with spatio-temporal smoke information mapping of sensor data into heat maps. The platform is suitable for different kind of sensors such as thermocouples or humidity sensors, but the main focus of this paper is on video sensing. There are three major steps in the fireGIS process: (1) the collection of low-cost video-sensor data for the smoke risk assessment, (2) the smoke map creation and (3) the spatio-temporal smoke behaviour analysis.

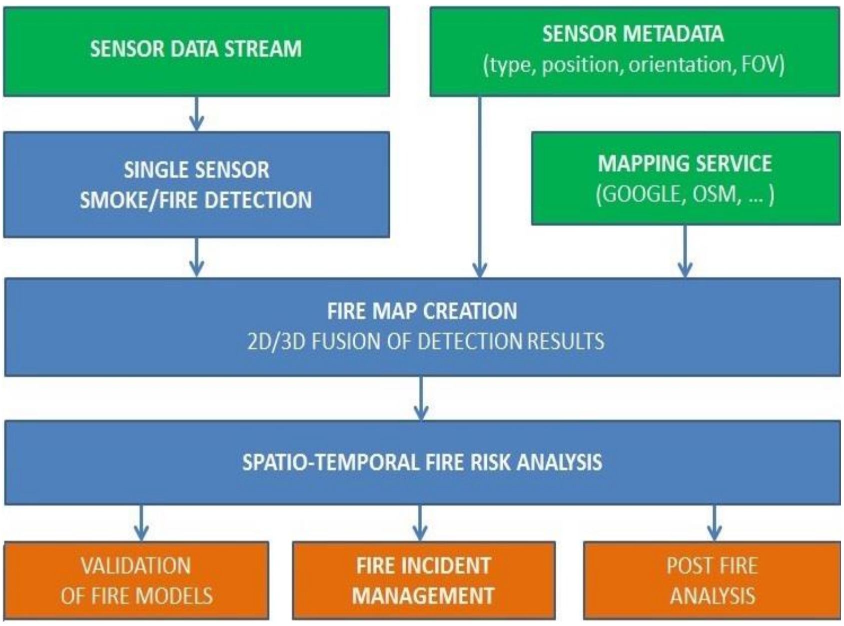

Figure 1: Generic fireGIS architecture for smoke behavior analysis

First, the platform needs to get metadata input about the video 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 platform. Currently there is still some manual intervention necessary to import all the data in the framework. In the future, better guidelines will be developed for describing how to incorporate this kind of data in an efficient automated way. In this step the user also needs to choose on which mapping service the results need to be shown. This could be done on global mapping services like Google Maps or OpenStreetMap (OSM), as shown in (Figure 2, left), but there exist also a possibility to show the final results on a 2D building location map, as shown in (Figure 2, right).

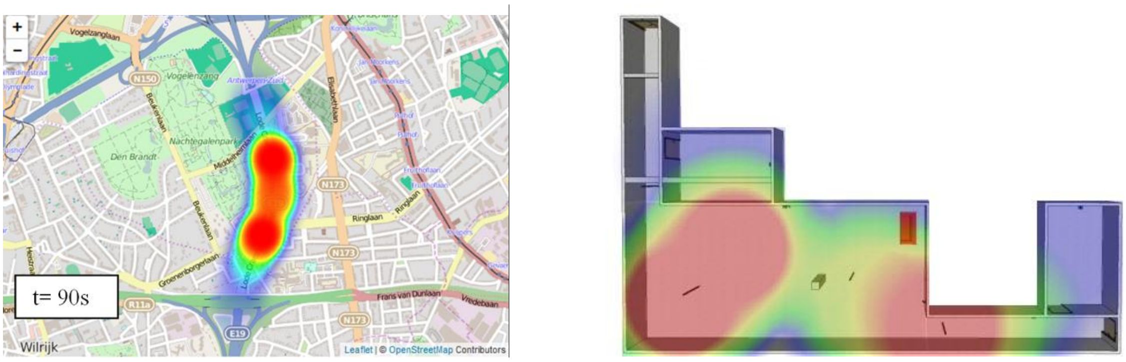

Figure 2: Mapping of smoke risk level on OpenStreetMap (left) and on building information map (right)

In the next step, i.e., after all the metadata information is provided in the system, the low-cost video smoke analysing algorithm starts investigating the streams and the smoke visibility is estimated. Subsequently, the sensor result are projected to the 2D map of the environment using the location metadata. In order to give an indication of the visibility (~ smoke risk), different colour codes ranging from green to red are used. 3D mappings are also possible and have already been investigated (Verstockt et al) [13].

Finally, by analysing the generated smoke visibility maps over time, a spatio-temporal analysis can be performed for the smoke spreading. This can be useful fast real-time information for incident management, but can also be used for post fire analysis. In future work, the system will also facilitate the linking of simulation models and real time smoke factors like proposed by (Koo et al) [5] and (Beji et al) [10]. Currently, the system is mostly used to perform post-fire analysis for real fire experiments, i.e., to see/monitor the impact of different smoke suppression and prevention mechanisms in a certain set-up.

4. REAL FIRE EXPERIMENTS

Over the last decade, several real fire sensing experiments have been performed, such as the Rabot (Beji et al) [14], Dalmarnock (Abecassis-Empis et al) [15], Tisova (Rush et al) [16] and Ulfiresafety tests (Kerber) [17]. However, performing these kind of tests is very expensive and the video streams are mostly a huge, unfiltered amount of data. It requires a lot of knowledge and time to interpret and visualize different set-ups. With our approach it is possible to reduce and structure this great amount of video data.

The evaluation of the fireGIS platform is done during real compartment fire experiments for the Belgian government (the set-up is shown in Figure 3). The goal of these fire experiments was to investigate the effectiveness of alternative fire suppression and fire security mechanisms in elderly facilities. Since there is a change in development and construction of certain set-ups (Koren) [18] and also an increasing rate of fatal fires, more knowledge of elderly home fires is necessary. Another facet is that more and more elderly homes are organised with large commonly spaces. Those are part of the evacuation and circulation routes, but they also contain electrical applications like cooking plates, dishwashers, refrigerators and so on. Currently, there is a lack of knowledge of fire behaviour in these environments. With the results of the real fire tests, new fire prevention rules will be defined.

The same sofa fire experiment was performed five times with each time a different fire suppression mechanism. The first experiment is called the ‘null’ experiment. In this case, there are no fire resistant doors and we only use a commercial fire detection mechanism. In the second experiment, we added fire and smoke resistant door. The doors are placed between the common space and the escape routes. The third experiment yields a smoke extraction system which is activated after the smoke detection. The fourth experiment is performed to see the effect of an automatic fire suppression to the smoke spread in the evacuation routes. The sprinkler system is automatically activated if the smoke reaches a certain temperature at the detector. Finally, the fifth experiment investigated the effect of a smoke extraction system in combination with an automatic fire suppression mechanism. Besides the visual video monitoring there were also temperature, CO and pressure measurements on several heights and places. Those are not taken into account in this paper, however, they can also be incorporated in the fireGIS platform and their combined multi-modal analysis will definitely improve the fire understanding. The visibility estimation which we extract from the video data will be explained more in detail in the next section.

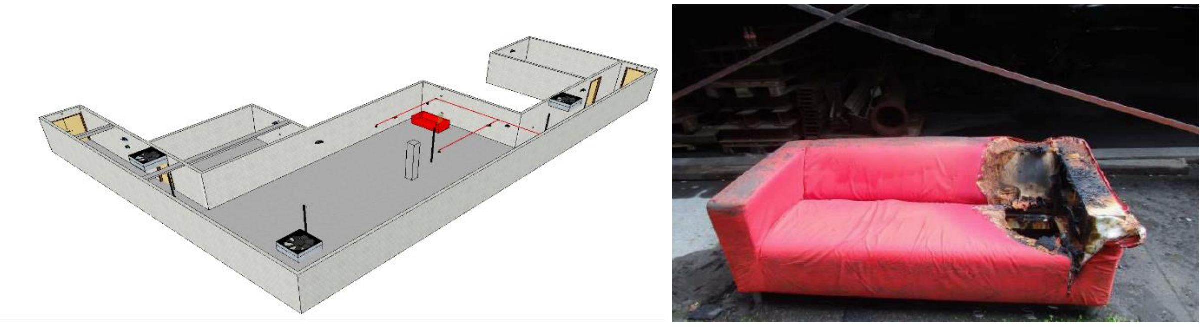

Figure 3:Overview of the multi-compartment set-up(left), burned sofa after the fifth case (right)

5. SMOKE ATTRIBUTES CALCULATION

5.1. Smoke visibility

The visibility is a major attribute for smoke behaviour analysis and smoke reading. Within this paper we use a video based visibility metric which is suitable for fire incident management (Vandecasteele et al) [19]. The visibility is estimated based on the sharpness and edges of the video frame. If the number of edges in a particular block of the image is decreasing, the visibility is also decreasing. The algorithm starts by converting the video to HSV-colour space and filtering out the value component. Next, a Canny edge detector (Canny) [20] is used to detect all the corners and edges in the image. The edge pixels in each block are counted and normalized. The normalization step is done by taking the ratio between the smoke and a non-smoke reference image. Finally, the result is stored as the visibility level ranging from 1 to 5, i.e., no-visibility and high visibility. Figure 4 shows the flowchart of the proposed visibility algorithm. It is important to remark that all these steps have a low computational cost which makes it possible to process the video frames in real-time. The evaluation of this visibility estimation is done by subjective analysis of video fragments of the real fire experiments. Furthermore, we have performed an subjective evaluation of the visibility by comparing it temporal with the visual output.

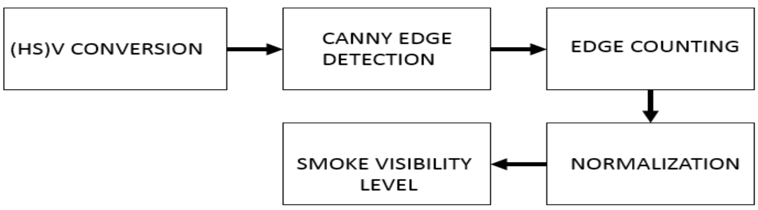

Figure 4: Flowchart for video based smoke visibility estimation

The visibility estimation is performed for each video sensor in the network. The corresponding spatio-temporal visibility estimations are stored in a XML-file with their corresponding camera metadata information. For each camera this incorporates the timestamp and the latitude/longitude coordinates of the sensor.

5.2. Smoke layer height

The second smoke feature that we investigate is the smoke layer height. A first approach to determine the layer interface height out of video sequences is proposed by (Beji et al) [11]. The algorithm focusses on the high energy lines of an image. Those lines are detected based on the energy derived from the discrete wavelet transformation (DWT) (Shensa) [21]. Based on the column wise energy maximization selection of the energy lines and a block-wise normalisation step, the energy profile line is constructed. Finally, by analysing the increased gradient of the energy profile, the smoke layer height can be estimated. The point where the gradient exceeds a predefined threshold is labelled as the smoke depth. The smoke layer height is estimated by subtracting the smoke depth from the height of the room. The workflow of the algorithm is shown in Figure 5.

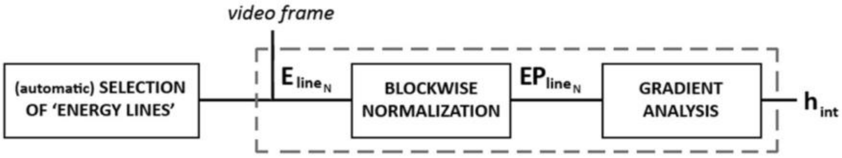

Figure 5: General scheme of video based smoke layer height estimation by Beji et al.

A second approach to estimate the smoke layer height out of video sequences is based on infrared video analysis. The approach that we propose here, (shown in Figure 6) is only suitable for spaces which are horizontally completely filled with smoke. A preliminary evaluation of this approach is done on a video set generated from real firefighter exercises in a container setup. Firstly, the frame is pre-processed by thresholding the pixels that correspond to the surrounding temperature and by applying a median filtering to remove the noise. Secondly, the white 'hot' pixels are detected and finally, the average location of the intersection line between the 'hot' and 'cold' pixels is determined. Based on the knowledge of the location of the ground place in the infrared image and the height of the room, the smoke height can be calculated.

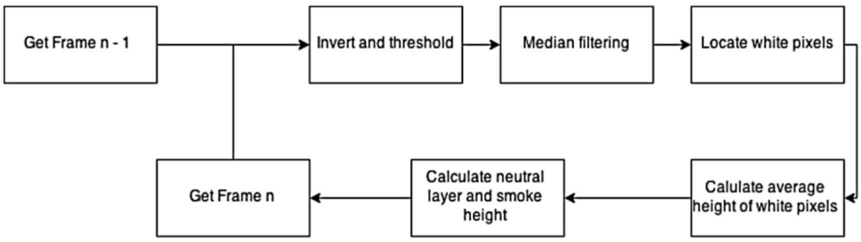

Figure 6: General schema of infrared based smoke layer height estimation

The mechanism will be further evaluated and optimized. Currently, the location of the ground plane needs to be predefined and the mechanism fails if there is some movement in the field of view. Future work will investigate how the smoke height could be estimated out of handheld, dynamic infrared imagers. Furthermore, spatial information of the building, the width, the height, will be incorporated in the algorithm.

A last approach for estimating the smoke height is not based on video sensors, but uses the output of a thermocouple tree. These values could be used to validate the video based smoke height estimations or this approach could be used in case there is no video sensing, but only thermocouple trees. There exist several methods to determine the smoke height out of the thermocouple values, such as the approaches proposed by (He et al) [22] and (Thomas et al) [23]. The height can for instance be estimated by taking the second derivate of the temperature profile (Tilley et al) [24]. The disadvantage of this approach is that a manual selection of the local maximum is necessary. A second method is the N-percent rule, where the smoke height is determined as a fraction of the temperature (Cooper et al) [25]. An important advantage of this method is that it is not time consuming and it can easily be used in the post-processing of simulation data. Future work will further evaluate numerical methods compared to video based estimations.

6. SMOKE BEHAVIOUR ANALYSIS

6.1. Heatmap visualization

The large amount of video data and smoke characteristics need to be visualized in a structured manner so that a fast decision making process is possible. In order to achieve this goal, the results of the generated smoke visibility and the smoke height estimations are shown on dynamic heatmaps. With these heatmaps it is easy to compare different set-ups, i.e., with and without smoke suppression, over time. The mapping could be done on a large 2D map or it could be done on a more detailed building information map of the location. Currently there are numerous studies who are describing the development of building information modules (BIM) (Volk et al) [26] and some of them describe the use of BIM in risk management analysis (Isikdag et al) [27]. However, there is a lack of applications who use real fire or real sensing data into the BIM module although there is already proven that a good knowledge of a building could help in the fire and smoke understanding (Mittendorf & Dodson) [28]. In the current version of fireGIS, the mapping of the smoke behaviour is done on a 2D map of the site as shown in Figure 7. Further work will focus on the integration and visualization of the smoke and fire data into 3D-BIM modules.

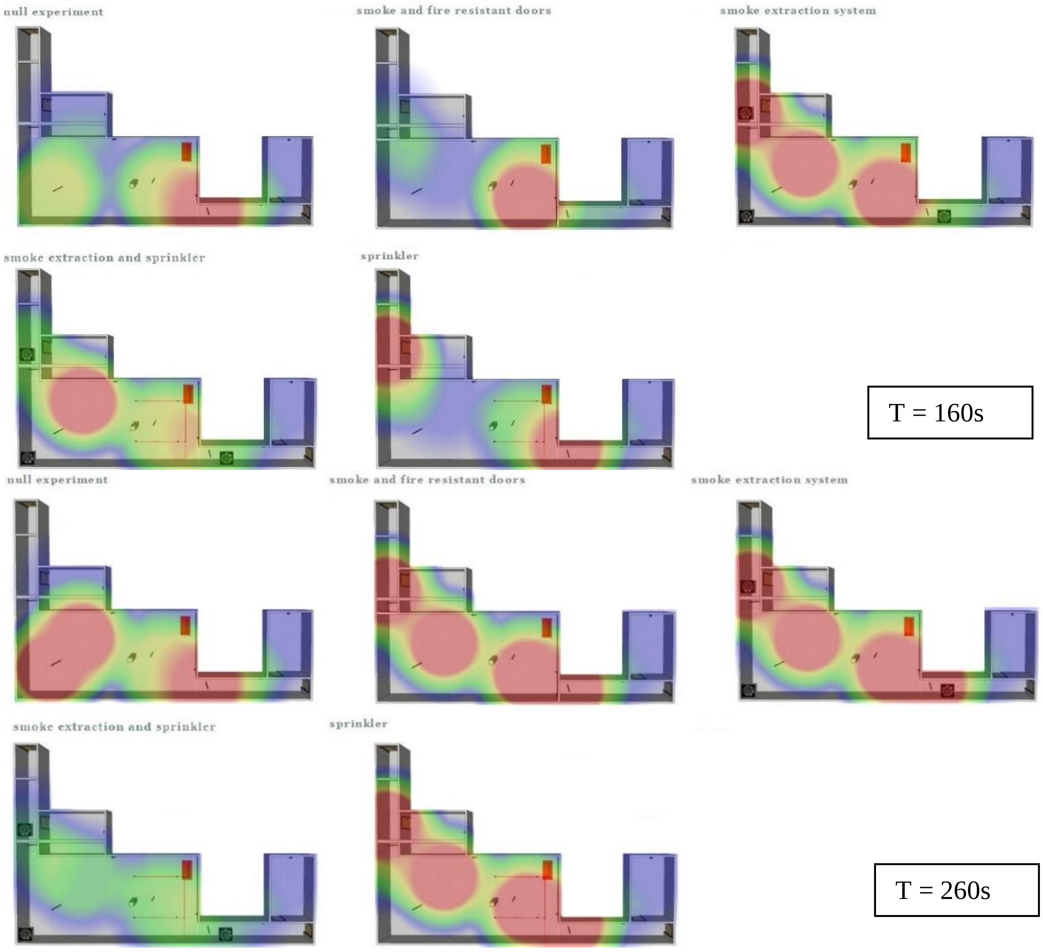

Figure 7: Spatio-temporal mapping of smoke behavior for real fire experiments

For the 2D mapping of the risk levels at a specific time-stamp, we developed a dynamic JavaScript-based web page. The web page makes use of the Leaflet.js and the Leaflet.heat heatmap plugin. It generates a heatmap layer on top of a map or given image. The input of the plugin is an array with latitude/longitude coordinates and an intensity level which corresponds to the level of the smoke characteristic for a certain timestamp.

With this visualization (as shown in Figure 7) it is easy to compare the different tests in the elderly home setup. Normally a manual, subjective evaluation would be done on different video streams and numerical simulated experiments. Certain calculations require a great knowledge of the fire and smoke behaviour and the final conclusions wouldn't be unique. Without the quantification of the smoke characteristics it would also be very hard to notify small, spatio-temporal changes.
By analysing the generated heatmaps and graphs over time it is possible to perform a spatio-temporal analysis of the smoke spreading and the smoke visibility. This makes the smoke reading process much easier and faster. Besides the visualization on a heatmap, there is also a possibility in the fireGIS platform, to generate temporal graphs of a certain smoke characteristic. User experience tests have already shown that the combination of these visualizations give more insights in the smoke behaviour compared to the stitched set of video images of a certain fire experiment.

6.2. Spatio-temporal visibility analysis

Besides the spatial visualization of the smoke visibility of a certain experiment there is also an option to visualize the temporal smoke visibility estimated from a particular sensor. This visibility could be visualised with a traditional graph (as shown in Figure 8) or with coloured slices (as shown in Figure 9). The red slices correspond to a very bad visibility, whereas the blue slices correspond to a clean visibility. It should be clear for the user of the platform that in the first case there is a strong increase in smoke and after 230 seconds there is no visibility anymore. In the second case with the smoke extraction and sprinkler mechanism there is a limited reduction in the smoke visibility, but the overall visibility during the experiment is good.

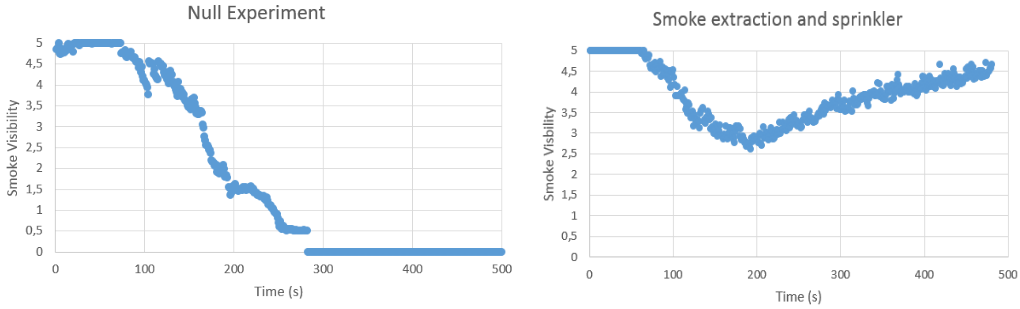

Figure 8: Temporal smoke visibility evolution for real fire experiments, traditional graph

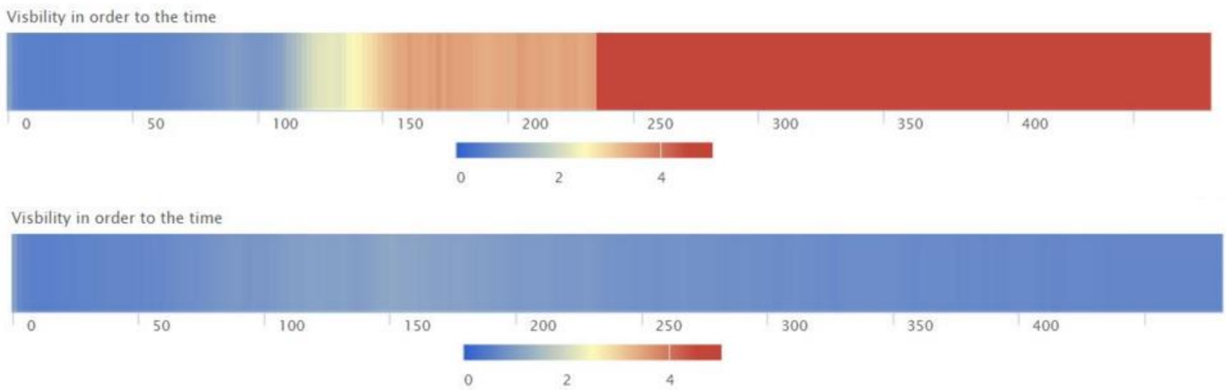

Figure 9: Temporal smoke visibility evolution for real fire experiments with colored slices

6.3. Spatio-temporal smoke height

Similar to the visibility there is also a possibility to visualize the smoke height with the fireGIS platform. Currently, the visualisation is only graph based. In the future we will integrate the smoke height in the building model. For the real fire experiments the smoke height is estimated with the N-percent rule of (Tilley et al) [24]. Figure 10 shows the temporal evolution of the smoke height for the null and fourth fire experiment.

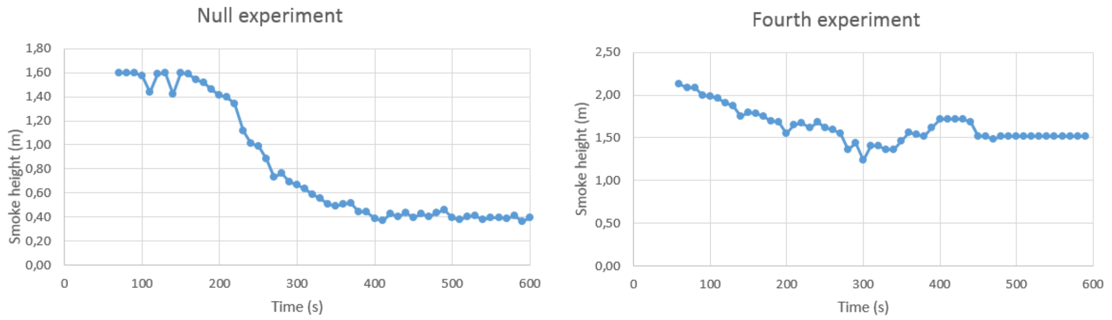

Figure 10: Temporal smoke height estimation for real fire experiments

6.4. Smoke behaviour analysis in real fire experiments

Our fireGIS platform facilitates the understanding of real fire experiments and is especially useful in visualizing the smoke behaviour during these tests. For the government and fire analysists it is more understandable what is happening with the smoke on a specific time or on a specific location. The spatio-temporal visualisation of the smoke visibility and smoke height makes it possible to see how fast the smoke is spreading. Also the moving direction and the thickness of the smoke can be easily understand. The final output of the platform is a web based visualization of all the video data and the estimated smoke characteristics.

Within the configuration panel of the web page the user has several options to change the visualizations. The user can visualise the spatio-temporal visibility, the smoke height, the thermocouple values (which are not further described in this paper) and the link to all the related video frames. Currently this workflow is not fully automated, but in the future an automated generator will be built.

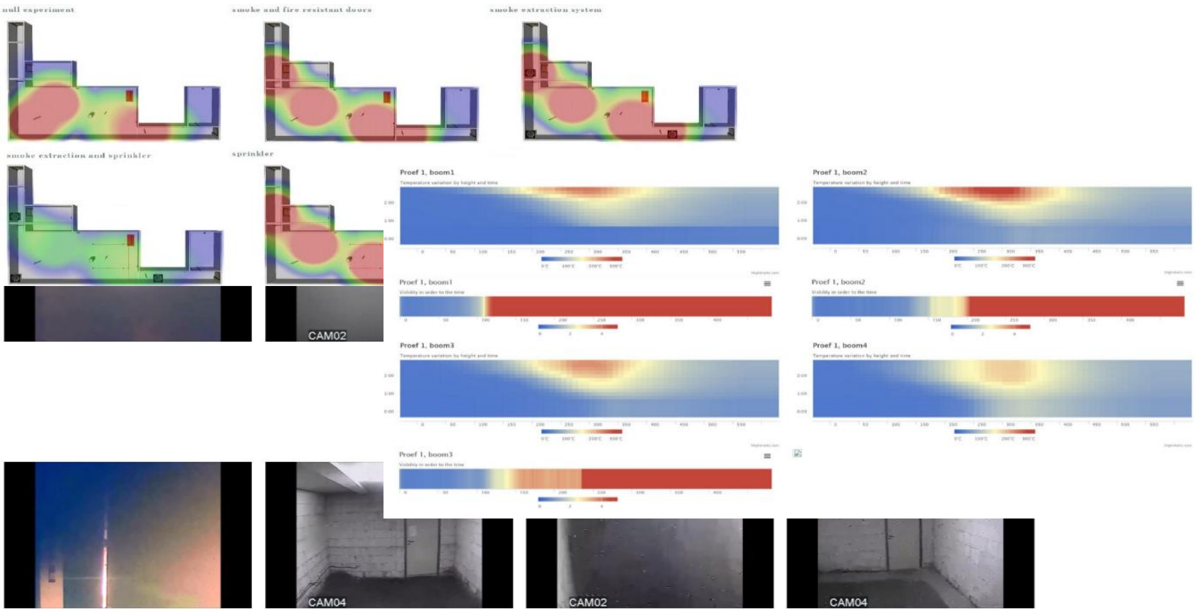

Figure 11: Some visualisations of the web based fireGIS module

7. CONCLUSION AND FUTURE WORK

This paper presents the use of the fireGIS platform for smoke behaviour analysis. The multi-view sensing based platform allows the generation of real-time heatmaps and graphs that show the space-time distribution of smoke risk levels and information across an area of concern. Within the paper we facilitate the smoke behaviour understanding for real fire experiments. A methodology for smoke visibility and smoke interface height estimation is proposed. Furthermore, the visualisation of fire and smoke risk maps is presented . Finally, the proposed workflow is evaluated within real fire experiments in an elderly home setup. Future work will focus on quantifying more parameters to describe the smoke characteristics out of video data. The turbulence and the volume of the smoke could for instance be determined. Furthermore, the use of handheld sensors (Paugam et al) [29] will be investigated in order to extend the fireGIS platform with mobile/dynamic sensors and to improve the dynamic smoke behaviour and smoke understanding process.

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REFERENCES

[1] Hartin, C. E. & Code, T., Fire Behavior.

[2] Fahy, R. F.,(2002), *US Fire Service fatalities in structure fires, 1977-2000*, NFPA.

[3] Othman, M. F. & Shazali, K., (2012), Wireless sensor network applications: A study in environment monitoring system, *Procedia Engineering*, 41, p1204-1210.

[4] Lorincz, K., Malan, D. J., Fulford-Jones, T. R., Nawoj, A., Clavel, A., Shnayder, V., Mainland, G., Welsh, M. & Moulton, S., (2004), Sensor networks for emergency response: challenges and opportunities, *Pervasive Computing, IEEE*, 3(4), p16-23.

[5] Koo, S.-H., Fraser-Mitchell, J. & Welch, S., (2010), Sensor-steered fire simulation, *Fire Safety Journal*, 45(3), p193-205.

[6] Çetin, A. E., Dimitropoulos, K., Gouverneur, B., Grammalidis, N., Günay, O., Habiboğlu, Y. H., Töreyin, B. U. & Verstockt, S., (2013), Video fire detection–Review, *Digital Signal Processing*, 23(6), p1827-1843.

[7] Grant, C. C., Jones, A., Hamins, A. & Bryner, N., (2015), Realizing the Vision of Smart Fire Fighting, *Potentials, IEEE*, 34(1), p35-40.

[8] Pereira, P., Cerdà, A., Úbeda, X., Mataix-Solera, J., Martin, D., Jordán, A. & Burguet, M., (2013), Spatial models for monitoring the spatio-temporal evolution of ashes after fire-a case study of a burnt grassland in Lithuania, *Solid Earth*, 4(1), p153.

[9] Miller, C. & Ager, A. A., (2013), A review of recent advances in risk analysis for wildfire management, *International journal of wildland fire*, 22(1), p1-14.

[10] Beji, T., Verstockt, S., Van de Walle, R. & Merci, B., (2014), On the use of real-time video to forecast fire growth in enclosures, *Fire Technology*, 50(4), p1021-1040.

[11] Drysdale, D.,(2011), *An introduction to fire dynamics*, John Wiley & Sons.

[12] Verstockt, S., (2011), *Multi-modal video analysis for early fire detection*Ghent University.

[13] Verstockt, S., Van Hoecke, S., Tilley, N., Merci, B., Sette, B., Lambert, P., Hollemeersch, C.-F. J. & Van de Walle, R., (2011), FireCube: a multi-view localization framework for 3D fire analysis, *Fire Safety Journal*, 46(5), p262-275.

[14] Beji, T., Verstockt, S., Van de Walle, R. & Merci, B., (2015), Global analysis of multi-compartment full-scale fire tests ('Rabot2012'), *Fire Safety Journal*, 76, p9-18.

[15] Abecassis-Empis, C., Reszka, P., Steinhaus, T., Cowlard, A., Biteau, H., Welch, S., Rein, G. & Torero, J. L., (2008), Characterisation of Dalmarnock fire test one, *Experimental Thermal and Fluid Science*, 32(7), p1334-1343.

[16] Rush, D., Lange, D., Maclean, J. & Rackauskaite, E., (2016), effects of a travelling fire on a concrete column-tisova fire test, *Applications of Structural Fire Engineering*.

[17] Kerber, S., (2013), Study of the effectiveness of fire service vertical ventilation and suppression tactics in single family homes, 17, p2013.

[18] Koren, M. J., (2010), Person-centered care for nursing home residents: The culture-change movement, *Health Affairs*, 29(2), p312-317.

[19] Vandecasteele, F., Beji, T., Merci, B. & Verstockt, S. (2015) Geographic reasoning on multi-sensor smoke spread data, *2nd European symposium on fire safety science*. Nicosia, Cyprus.

[20] Canny, J., (1986), A computational approach to edge detection, *Pattern Analysis and Machine Intelligence, IEEE Transactions on*(6), p679-698.

[21] Shensa, M. J., (1992), The discrete wavelet transform: wedding the a trous and Mallat algorithms, *Signal Processing, IEEE Transactions on*, 40(10), p2464-2482.

[22] He, Y., Fernando, A. & Luo, M., (1998), Determination of interface height from measured parameter profile in enclosure fire experiment, *Fire Safety Journal*, 31(1), p19-38.

[23] Thomas, P., Hinckley, P., Theobald, C. & Simms, D., Investigation into the flow of hot gas in roof venting, *Fire Research Technical Paper*(7).

[24] Tilley, N., Rauwoens, P. & Merci, B., (2011), Verification of the accuracy of CFD simulations in small-scale tunnel and atrium fire configurations, *Fire Safety Journal*, 46(4), p186-193.

[25] Cooper, L. Y., Harkleroad, M., Quintiere, J. & Rinkinen, W., (1982), An experimental study of upper hot layer stratification in full-scale multiroom fire scenarios, *Journal of Heat Transfer*, 104(4), p741-749.

[26] Volk, R., Stengel, J. & Schultmann, F., (2014), Building Information Modeling (BIM) for existing buildings—Literature review and future needs, *Automation in construction*, 38, p109-127.

[27] Isikdag, U., Underwood, J. & Aouad, G., (2008), An investigation into the applicability of building information models in geospatial environment in support of site selection and fire response management processes, *Advanced engineering informatics*, 22(4), p504-519.

[28] Mittendorf, J. & Dodson, D.,(2015), *The Art of Reading Buildings*, Fire Engineering Books.

[29] Paugam, R., Wooster, M. J. & Roberts, G., (2013), Use of handheld thermal imager data for airborne mapping of fire radiative power and energy and flame front rate of spread, *Geoscience and Remote Sensing, IEEE Transactions on*, 51(6), p3385-3399.