

A Smoke Type Classification Concept for Video Fire Detection

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Abstract

Video Fire Detection (VFD) is an emerging topic. It is typically divided in two parts, flame detection and smoke detection (VSD). In VSD the focus usually lied on diverse properties of smoke and how to combine them to reliably identify smoke in a video sequence. The goal is to find unique properties, which every smoke event has in every situation. This paper describes a different approach. It provides a smoke type classification concept due to temporal and spatial behavior and visual properties in a video sequence.

This novel classification concept divides the visual appearance of smoke in four different categories. Using this concept we analyze representative video records of smoke events and map the smoke types to each event. We find that it is possible to map at least one type to each event and that there are useful conclusions for VSD concerning prioritization and correlation of the smoke types. Furthermore for each smoke type own requirements can be formulated and algorithms can be developed and tested separately.

Keywords: video fire detection, video smoke detection, smoke types, smoke classification

Introduction

An overview of developed methods and their boundaries is provided by [1] and [2]. The challenge is to find unique temporal and spatial properties of smoke, which differentiate a smoke event from other events in a video sequence. The problem is that smoke can appear in many variations, e.g.: transparent, opaque, continuous rising, growing in all directions, slow, fast. It is hardly possible to find properties that work for every smoke event in every situation.

Our approach divides the smoke detection problem into four smoke type classes: directed expanding, undirected expanding, background flickering and ambient smoke, which are described in chapter 4. We analyze these smoke types with respect to detection algorithms. Features from literature are suggested for each smoke type and a subjective estimation is given, which smoke type is the most difficult to detect with VSD algorithms. This shows, that the proposed smoke type classification concept allows a separation of algorithms: Formulating requirements, developing and testing.

100 representative smoke events caused by different smoke sources are recorded. We choose different locations, view angles for the camera and environment properties. To each smoke event at least one observed smoke type is mapped. This underlines that the classification concept is sufficient to cover any kind of smoke events. In addition the appearance and statistics of the smoke types are analyzed. The results allow a prioritization, which smoke type a VSD system should detect and give hints how to combine algorithms for different smoke classes.

The paper is structured as follows: In chapter 2 we describe our video material and experiments, on which the classification is based. Secondly, in chapter 3 we give a detailed description for every class under the aspects motion, smoke density and environmental conditions. Based on this features for different smoke types are suggested. Afterwards we analyze the appearance frequencies and correlations between the classes statistically based on the gathered video material in chapter 4.

Video material

To get representative video material we recorded 100 smoke events with a video camera. For smoke sources we used different smoke combustible material like wood (open flame, smoldering), liquids (ethanol, gasoline, decalin), cotton and paper. Most of these materials are used for certification of ordinary smoke detectors according to EN54 [3]. Our experiments were placed at different locations like an underground garage, factory halls, a shopping center, a powerhouse, an agricultural barn or a bullfighting arena. The videos were taken under different light and wind conditions. The cameras were placed in various view angles and heights with respect to the smoke source. In many recordings we placed different sized objects between the smoke source and the camera.

Description of smoke classes

According to our experiments we can divide the smoke behavior into four classes, namely: directed expanding, undirected expanding, background flickering and ambient smoke. We describe these classes under the aspects: motion and growing behavior, smoke density and

texture. These aspects are subjectively perceived visual properties. For each class features from literature are suggested.

Directed expanding smoke has a main motion and growing direction. The motion direction is diagonal or straight upwards. Directed expanding smoke usually appears directly over the smoke source under calm wind conditions and forms a column in the rising direction. At high smoke densities ($> 70\%$) the smoke column has a strong inner structure with many edges which seem to flow in the motion direction. At lower smoke densities (between 30% and 70%) the smoke is rising up in streaks. To analyze this smoke type optical flow based features can be used, for example see [4].

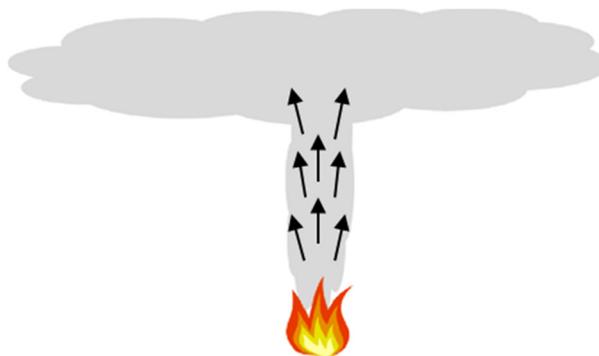


Figure 1. Schematic illustration of directed expanding smoke.



Figure 2. Example for directed expanding smoke. The three frames extracted within 5 s from a smoke event show a constant smoke column with rising smoke in it.

Undirected expanding smoke has no clear motion or growing direction. It usually appears in the border regions of a smoke column, in areas with turbulent wind or under objects. You can compare the shape of undirected expanding smoke to a plume. At high smoke densities ($> 60\%$) there is strong turbulent motion, appearing and disappearing edges and streaks in the inner regions of the plume. At lower smoke densities (between 30% and 60%) the smoke plume has a homogenous inner structure, which grows undirected.

For undirected expanding smoke it is natural to combine texture based features like wavelets and shape feature like irregularity.

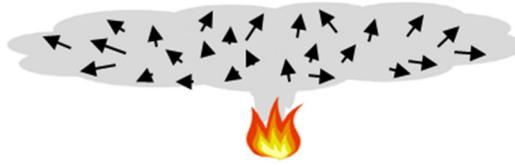


Figure 3. Schematic illustration of undirected expanding smoke.



Figure 4. Typical undirected expanding smoke event.

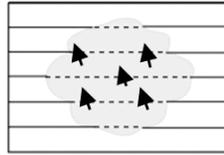
Background flickering smoke is very thin (smoke density < 30 %). All background details stay visible, but they seem to flicker, while smoke passes them. Flickering is the frequent change of saturation or edge contrast. Background flickering smoke has no clear shape. It usually appears as an extension of a smoke column or plume, over hot flames or as an outlier far away from the smoke source. Features derived from a temporal frequency analysis can indicate the flickering. This smoke type is hard to detect, since it is difficult to distinguish it from noise.

Ambient smoke gathers under an object, normally the ceiling. The smoke density increases downwards and sideways over time until you can hardly see any background details. Ambient smoke is homogenous without edges or structure. It has no clear shape. Temporal and spatial features from energy analysis could be used to detect ambient smoke. Detection of ambient smoke is difficult, since this smoke type has no significant texture or movement. Furthermore light changes can lead to similar behavior.



10s →

Figure 5. BGF example. Three images taken in a 10s time interval from a smoke event. One can see the change in contrast at detailed edges.



background
background flickering



Figure 6. Schematic illustration of background flickering.

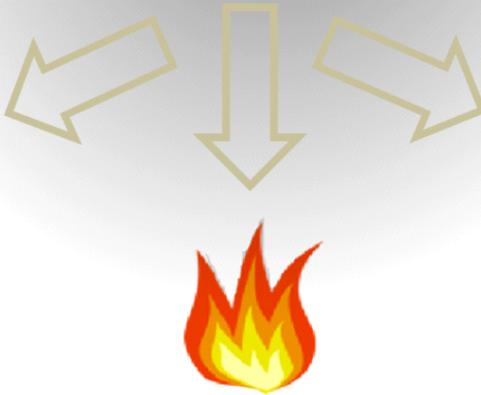


Figure 7. Schematic illustration of ambient smoke.



Figure 8. Typical ambient smoke event, of which three key stages are shown.

The proposed smoke type classification has great benefits for VSD. By separating the problem of VSD according to the proposed classification it is possible to formulate requirements for each class. For example: In contrast to very dense directed expanding or undirected expanding smoke we assume, that it is very hard to detect background flickering smoke in a video sequence, since it hardly differs from the ordinary background and noise. Thus we allow the algorithm a high verification time. Moreover it is much easier to find and describe properties for each single class and combine them in class algorithms, which work for every smoke event that fits into this class. E.g. for undirected expanding it seems natural to investigate the shape and inner structure of the smoke plume, whereas for directed expanding smoke it is rather preferable to calculate the velocity and direction of the smoke column. Furthermore for each class test cases can be developed to verify the class algorithm.

A combination of all class algorithms is a promising approach for reliable VSD systems.

Statistical analysis

We use the proposed classification concept to label our smoke video material. A smoke event has stages with different behavior, so sometimes more than one smoke type can be mapped to an event. For example a smoke event which has a column with directed expanding smoke over the source could also have undirected expanding behavior in a sufficient distance to the source. We assigned the appearing smoke class(es) to each event and analyzed the results with respect to VSD systems. Table 1 shows the results in a double cross table. The abbreviations are explained in the annotations.

Table 1: Cross table of observed classifications (raw data). DE stands for directed expanding, UE for undirected expanding, BGF for background flickering and A for ambient smoke. The red numbers are the sums of columns and/or rows.

		BGF		not BGF		
		A	not A	A	not A	
DE	UE	10	14	1	1	26
	not UE	15	22	1	1	39
not DE	UE	4	18	1	1	24
	not UE	1	9	1	0	11
		30	63	4	3	100

We could map at least one smoke type to an event. This underlines that the proposed classification concept is sufficient to describe every smoke event. In order to infer conclusions for VSD from this raw data we provide some relative appearances in Diagram 1.

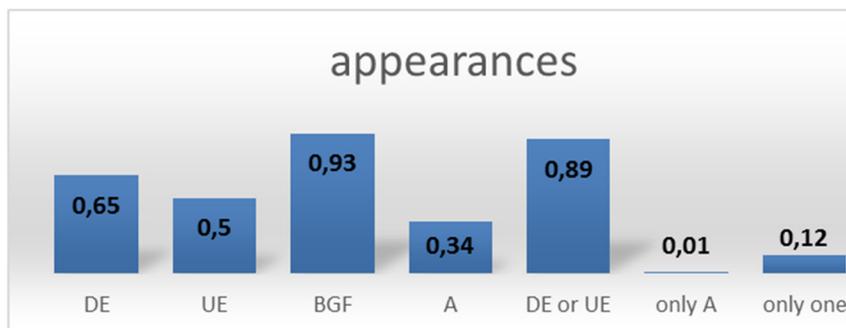


Diagram 1. Relative appearances for each class and some meaningful combinations of those.

These appearances allow a prioritization, of which smoke a VSD system should detect. At first a VSD system should concentrate on directed expanding smoke, which covers about 65 % of all recorded smoke events. In combination with undirected expanding features a VSD system can detect about 89 %. These smoke types are estimated to be the easiest to detect. In 93 % one can observe background flickering and therefore it is a good indicator for smoke. Since reliable detection of background flickering is difficult and hard to differ from non-smoke events like noise, it is not clear, if it is preferable to concentrate on this smoke type. In about 12 % of the cases a VSD system can use only one class to detect smoke. In the other cases one can combine the class properties to increase the reliability.

In only 1 % of all smoke events ambient is the only class left for smoke detection, which is thankful, since it is the worst case scenario in VSD.

Conclusion

This paper proposed a concept of separating the VSD problem into four classes. Each smoke type has a special temporal and spatial behaviour. In contrast to common VSD approaches in literature our concept enables to develop algorithms for each class. This concerns requirements, features and tests. It is shown, that this concept is sufficient to cover a representative set of smoke event records. Furthermore a statistical analysis yields a prioritization and correlation of the smoke classes. The investigation and development of algorithms for each class is left to future work.

References

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