Visual Smoke Density Measurement for Video Smoke Detection

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Abstract

The research focus in Video Smoke Detection (VSD) usually is on temporal and spatial properties of smoke and how to combine them in algorithms to reliably identify smoke in a video sequence [1]. There has been fewer work on visual properties of smoke during a smoke event over time. Inspired by the human perception of smoke this paper presents a new concept to measure the visual smoke density in a video sequence. This measure can be used to describe limits respectively performance of VSD algorithms or to define requirements for VSD systems. Additional the proposed measurement method is suitable to define standards in VSD. To analyze this, video frames taken from EN54 test fires are analyzed. After that our measurements are compared to MIREX-measurements, which is an optical sensor for smoke density used to define test fires in EN54.

Keywords: video smoke detection, visual smoke density, EN54, contrast decrease, edge detection

Introduction

The most crucial visual property of smoke recognized by the human eyes is the smoke density. The visual smoke density can be defined as decrease of background details, which stay visible through smoke. The visual smoke density is a local property. That means, it changes from region to region and is not homogenous distributed in an image.

A smoke column is not comparable to ordinary objects with fixed shape and stationary properties. Smoke changes over time in shape, inner structure and contrast. When it forms plumes, a smoke event can be perceived as two or more objects. All this properties can be described by temporal and spatial visual smoke density behavior. To quantify these observations we develop a model for the visual smoke density based on the human perception and define a measure for it. There are several benefits to have such a measure: It can be used to describe, in which situations VSD features work. For example texture based features (e.g. wavelets) only work, when smoke covers the background completely, which is indicated by high visual smoke density. Beyond that the performance and limits of different algorithms can be compared. Second, we can use the visual smoke density measure to evaluate test fires to certify VSD systems, comparable to the MIREX, which is used to evaluate test fires for ordinary smoke detectors. To show these benefits we analyze TF1 and 2 of EN54 test fires recorded in a fire lab using the proposed measure and compare our results to the MIREX.

The paper is structured as follows. In chapter 2 a robust video based measurement method of smoke density is provided, which uses the edge smoothing property of smoke. After this we use our method to investigate TF1 and TF2 of EN54 test fires. These are described with focus on the temporal and spatial behavior in chapter 3. In chapter 4 section we analyze the visual smoke density in different regions of the smoke column and map our observations to the described smoke behavior. After this we compare the results of our smoke density measure to the MIREX in chapter 5.

Measurement Method

The smoke density is usually defined as optical density. For example the MIREX emits a light beam of power P_0 and measures the left power P after passing a distance d. The optical density o_S of smoke is defined as

$$o_S = \frac{10}{d}\log_{10}\left(\frac{P_0}{P}\right) \qquad [\mathrm{db/m}]. \qquad \text{Eq.1}$$

This Method is described in [2]. Later this formula is used to compare our measurements to the MIREX. The basic idea of our method is inspired by the human visual system: edges are smoothed, when smoke covers them.

Fig.1. Increasing smoke density reduces edge strength.

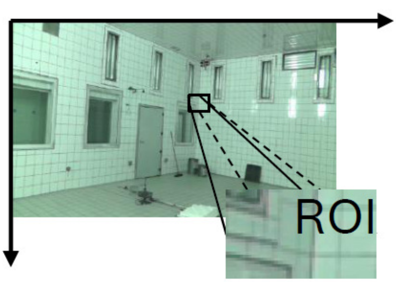

Fig.2. Region of interest (ROI) for visual smoke density measurement.

Figure 1 shows how the increasing smoke density decreases the intensity in the pixel neighborhood of an edge. Therefore we observe the relative change of edge strength between a reference image without smoke and an image in which we want to measure the visual smoke density.

Let $R = \{(x, y)|(x, y) \in \mathrm{ROI}\}$ be the region of interest (ROI), of which we want to measure the smoke density. One example is shown in figure 2. First we define the edge strength $e_{(x,y)}(n)$ for a pixel $(x, y) \in R$ in the *n*-th frame as

$$e_{(x,y)}(n) = |\Delta_k * I_n(x, y)|, \qquad \text{Eq.2}$$

where $I_n(x, y)$ is the intensity image of the *n*-th frame at pixel (x, y), Δ_k is the $k\mathbf{x}k$ laplacian kernel (k odd), and $*$ the finite discrete convolution operator. For example the laplacian kernel Δ_k for $k = 3$ is

$$\Delta_3 = \begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}. \qquad \text{Eq.3}$$

$e_{(x,y)}(n)$ is a discrete approximation of $|\Delta I_n(x, y)|$, where Δ is the laplacian operator, which takes high positive or negative values at positions (x, y) with strong spatial changes of intensity. To the structure of Δ_3 this property can easy be varified, since $\Delta_3 * I_n(x, y)$ is near zero in homogenous intensity regions and takes high positive or negative values, if the intensity jumps next to pixel (x, y). So $e_{(x,y)}(n)$ is a suitable measure for the edge strength. We conclude: the greater the absolute values of $\Delta_k * I_n$ in the ROI R the stronger are the edges in this region. We now can define a measure for the mean edge strength $e_R(n)$ of our ROI in the *n*-th frame as

$$e_R(n) = \frac{1}{|R|} \sum_{(x,y)\in R} e_{(x,y)}(n) \,. \qquad \text{Eq.4}$$

Where $|R|$ are the number of pixels in our ROI. Our method for visual smoke density measurement can be summarized as follows: At the beginning we have to specify a reference frame n_0, which should be chosen carefully with no smoke or moving objects in the ROI and strong visible edges. After this we can define the relative decrease of the edge strength of the reference frame $e_R(n_0)$ to the observed frame $e_R(n)$ as visual smoke density $\rho_s(n)$ of *R* in frame *n*

$$\rho_s(n) = 1 - \frac{e_R(n)}{e_R(n_0)}. \qquad \text{Eq.5}$$

Note that $\rho_s(n)$ could also be negative, if $e_R(n) > e_R(n_0)$. This especially happens, if the smoke has a fragile structure and forms its own edges. Another challenge is, that the edge strength $e_R(n)$ could also be interpreted as a measure for spatial intensity variations.

Intensities in a video sequence can be influenced by different sources, e.g. light changes, self-calibration of the camera or general noise. In order to get rid of some influences and the own edge effect we perform two extra steps. First we use mean intensities $\overline{I_n}$ over a frame sequence with duration s instead of a single frame intensity I_n

$$\overline{I_n} = \frac{1}{s}\sum_{m=0}^{s-1} I_{n+m}. \qquad \text{Eq.6}$$

This averages out the own edges and suppresses light and noise effects. The length s of the video sequence over which we calculate the mean image should be chosen depending on the framerate fps of the video and a time interval dt

$$s = \mathrm{fps} \cdot \mathrm{d}t. \qquad \text{Eq.7}$$

Secondly we restrict our ROI R to a region $\tilde{R} = \{(x,y) \in R | e_{(x,y)}(n_0) > \alpha e_R(n_0)\}$ which contains all pixel with the strongest edge strength in the reference frame in R and is controlled by α. We define our improved smoke density measure

$$\tilde{\rho}_s(n) = 1 - \frac{e_{\tilde{R}}(n)}{e_{\tilde{R}}(n_0)}. \qquad \text{Eq.8}$$

This method provides reliable values for the visual smoke density choosing $k = 3$, $\mathrm{d}t = 5s$ and $\alpha = 0.2$.

Smoke behavior of EN54 TF

The goal is to get comparable results of smoke behavior. So we investigate TF1 and TF2 from the EN54 test fires, which are used to certificate ordinary smoke detectors. These test fires are defined in [3]. Before we use the proposed method to get quantitative results of the visual smoke density, we take a look at the qualitative smoke behavior that can be seen in the test videos. For our measurements we use video sequences taken in a fire lab under same light conditions and camera positions.

Figure 3 describes the setting. The dimension of the fire lab is in compliance with EN54 standard. The fire and smoke source is positioned in the middle bottom of the room and the camera is in the front left corner with 28° viewing angle on the source. The MIREX is positioned under the ceiling.

TF1 is an open wood fire. It is hardly possible to see any smoke rising, but after a while one can recognize a continuous increase of dense particles which starts at the ceiling and slowly moves down and sideways.

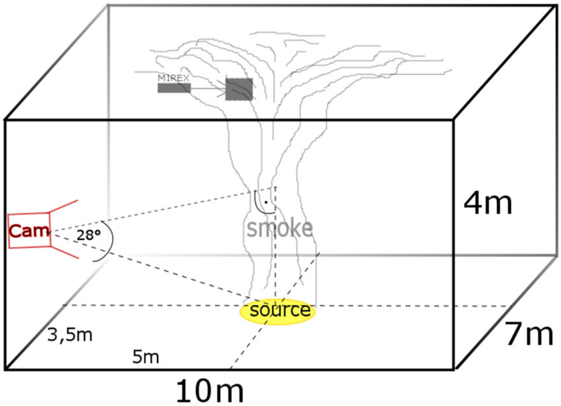

Fig.3. Lab settings.

TF2 is a smoldering fire. Some wooden sticks are heated by a hot plate producing light greyish smoke without any flame. One can observe the way of smoke movement and it is continuously rising till it reaches the ceiling. There it gathers and moves sideways. One can also recognize that the particle dense grows starting under the ceiling and moving downwards.

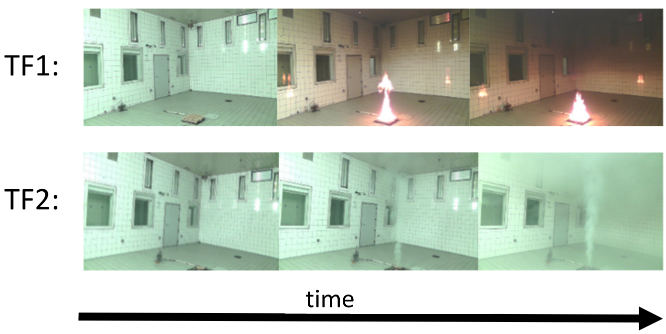

Fig.4. Key stages of TF 1 and 2.

Smoke analysis

The recorded videos are analyzed with the proposed measurement method for the visual smoke density. The ROIs have to be set, such that we get comparable results. Following our qualitative results we expect increasing smoke density in a column from the smoke source to the ceiling and in some cases increasing particle density under the ceiling in an area sideways from the source.

Figure 5 shows a suitable choice for regions in which we selected ROIs. According to our measurement method we choose regions with strong edges. Another challenge is to minimize light fluctuations, which could be influenced by flame flickering on the one and smoke covering of the light sources in sight of the camera on the other hand. To minimize the effect of flame flickering the illumination has to be as strong as possible.

This can be controlled by the strength of artificial light sources. So we turn the lights left and right of the camera on and the lights in sight of the camera off. M1-M3 represent the smoke column. In L1 and R1 the lateral movement will be observeable. In L2, L3, R2 and R3 we may observe the down moving increase of particle density.

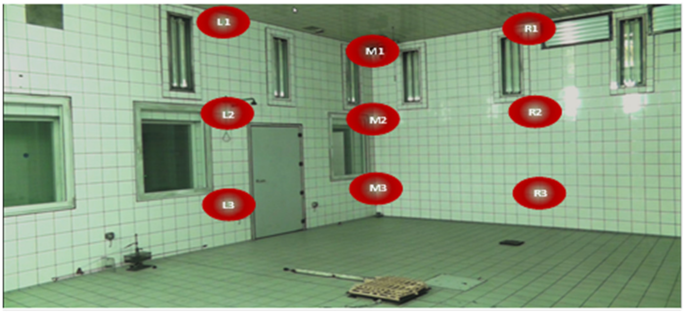

Fig.5. ROIs.

Figure 6-7 shows the results of the measurements.The time window of the smoke event differentiates between the test fires. The solid lines show the smoke density development directly under the ceiling, the dashed lines the development in middle height and the dotted lines show the development near the ground. The color represents the position relative to the smoke column over the source, red represents the measurements in the column, green left of the column and blue right of the column. General saying, we find the expected spatial and temporal behavior of smoke in each diagram.

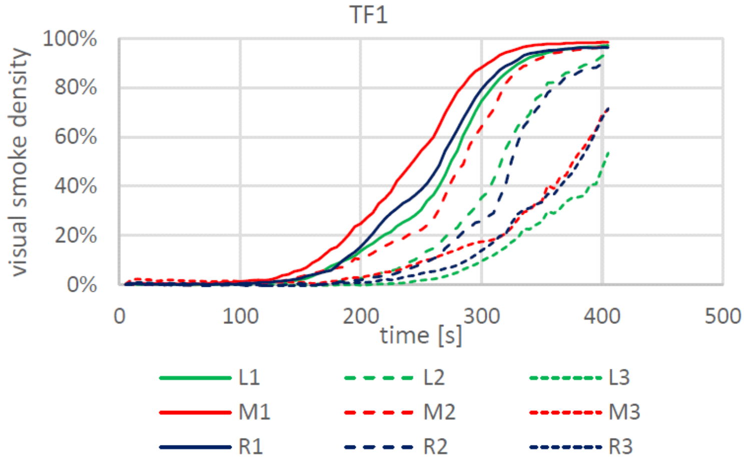

Fig. 6. TF1 measurement.

Comparing the measurement results of TF1 we can see the sideways and downwards movements very well. The temporal curve shape can be compared to sigmoid (S-shaped) growth: first the growth rate increases and after a turning point it begins to decrease. This qualitative curve form behavior can be observed at every TF fire.

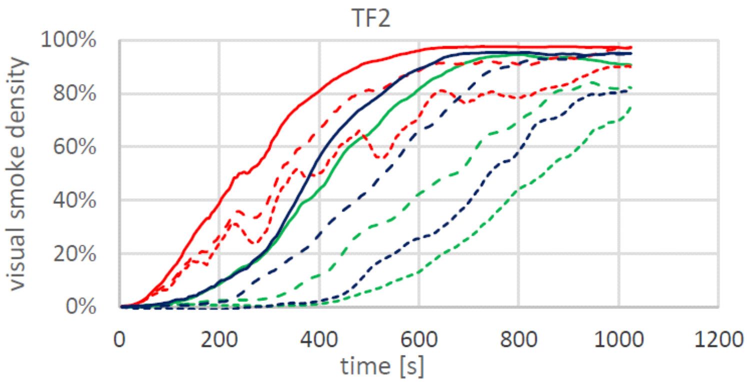

Fig. 7. TF2 measurement.

The TF2 plots in figure 7 show, that the smoke density under the ceiling begins a bit earlier to increase compared to TF1 due the property that TF2 is a smoldering fire with directly visible smoke particles, but it needs much longer to cover the edges completely.

These strong relation between the subjective perception of smoke behavior and the results of the visual smoke density measurement underlines the reliability of our measure. It is suitable to describe the temporal and spatial properties of smoke in a video sequence. So one can use this measure to quantize requirements for VSD algorithms and to describe their performance.

Comparison to MIREX

The MIREX is a measurement apparatus placed centrally over the smoke source at the ceiling. It measures the optical density on a logarithmic scale according to equation *(1)* with *d=1m*. This is not the whole diameter d_c of the smoke plum seen by the camera. d_c depends on the ROI, e.g. $d_c(M1) > d_c(M2)$. To make the measurement results of the MIREX comparable we transform the results of the optical density o_s into the power decrease ratio r_P

$$r_P := 1 - \frac{P}{P_0} = 1 - 10^{-d_c o_s/10} \quad . \qquad \text{Eq.10}$$

This quantity is rather comparable to the visual smoke density. We now plot the middle Region M1-M3 and compare it to the MIREX result choosing different d_c.

The Diagrams in figure 9 show an obvious correlation. Due to the fact that the MIREX sees another smoke diameter than the camera, the values differ, but it should be possible to fit the curvatures by choosing a sufficient d_c. This correlation shows the possibility to choose the proposed measure for the visual smoke density to define a smoke behavior for VSD standardization.

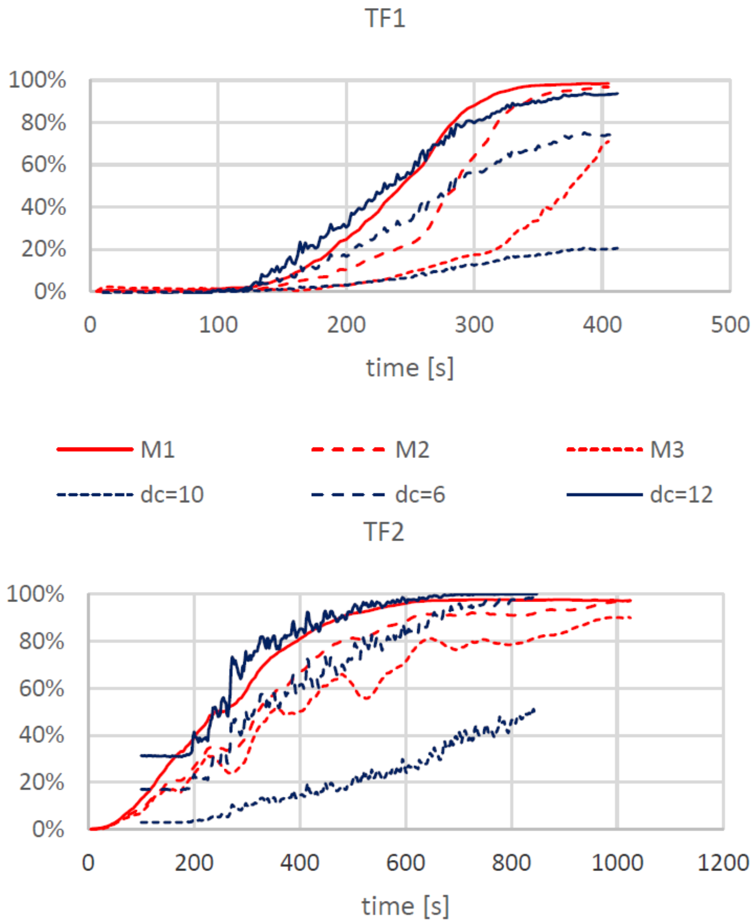

Fig. 8. Visual smoke density MIREX comparison.

Conclusion

In the proposed paper we presented a novel measurement method for visual smoke density, which is inspired by the human perception. It was applied to EN54 test fires and delivered reliable results in temporal and spatial domain. Thus this method can be used to describe smoke behavior in a video recorded fire event. It also enables to quantify the limits of features designed to detect smoke in a video sequence.

Another benefit is that it could be a starting point to define a smoke behavior for certification of VSD algorithms. This possibility is underlined by the strong correlation to MIREX measurements, which are used to define EN54 test fires.

References

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