Thomas G. Cleary
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899 U.S.A.

Video Detection and Monitoring of Smoke Conditions

Abstract

Initial tests have been performed to assess detection limits and smoke obscuration monitoring for a video scene under different lighting and smoke concentration conditions. An illuminated exit sign located in the fire emulator/detector evaluator duct was used as the scene. A fixed gain, black and white CCD camera, coupled to a manual-focus, manual-iris video zoom lens was used. The lens itself was attached to a rigid boroscope, which penetrated the duct and viewed the exit sign from a distance of 2 m. Flaming soot, smoldering wood smoke, and ISO test dust were used to obscure the scene. Repeated tests were performed with the external scene lighting turned on or off. Scenes ranged from smoke/dust free conditions to a completely obscured exit sign. Analysis of the data shows that a CCD camera pointed at a continuously illuminated source, like an exit sign, can provide an indication of obscuring aerosols in the scene (i.e. detection). Furthermore, an assessment of the visibility conditions can be obtained from the scene under fixed lighting conditions. Analysis of the loss of contrast between the illuminated letters and the background of the sign provides a more general assessment of visibility conditions.

Introduction

Building video surveillance via human monitoring of multiple locations was the norm just a few years ago. Now, automatic video image processing and decision algorithms exist for many conditions including, traffic control, perimeter security, and even facial recognition. Essentially, any routine decision that a human observer makes can be replaced with some level of success by a dedicated machine vision system. Fire detection schemes employing video cameras have been developed and deployed in various environments. Security concerns will only increase the use of video monitoring in buildings, so it make sense to maximize that infrastructure investment. Augmenting existing fire detection systems with video detection may increase sensitivity to real fire events. Another potential benefit would be real-time assessment of visibility conditions in fires to help with egress and search and rescue. There is little quantitative data in the literature relating the video image properties to smoke obscuration levels.

Wieser and Brupbacher [1], give a brief description of a design based on loss of contrast due to smoke. They also discuss calibration issues, and the challenges of deploying a design in a road tunnel. Jin's work on visibility through smoke related the amount of smoke to the visibility distance of internally illuminated and reflecting signs [2]. He also postulated the main reasons for decrease in visibility through smoke as (1) a reduction in light intensity of the object (sign) and background due to the obscuring smoke, and (2) scattered light off smoke particles from other light sources that reach the subject's eye. Collins *et al.* [3] studied exit sign visibility in clear and smoke obscured conditions and observed that sign luminance, and to some extent uniformity and contrast, are important in sign visibility in smoke. Ouellette's [4] study on exit sign visibility in smoke examined the effects of ambient illumination and suggested that brighter exit signs are needed to compensate for the luminous veil created by ambient lighting when smoke is present, or lighting along lines of sight to exit signs should be reduced when smoke is detected.

The experiments conducted in this study were designed to assess the ability to use video images to detect the level of different types of smoke and dust in the path from a viewing location to a constantly illuminated target, and to predict the visibility conditions over that path length.

Experimental

The fire emulator/detector evaluator [5] was used to provide different volumes of uniform smoke concentration. The test section was modified to allow viewing of an internally lit exit sign through the smoke. A schematic of the test section is shown in Figure 1. Smoke enters from the right and exits through a 90^{o} elbow at the left side. A diode laser beam (635 nm) travels from the end of the duct to a mirror located above the center of the exit sign back to a photodetector. The light transmission path length is

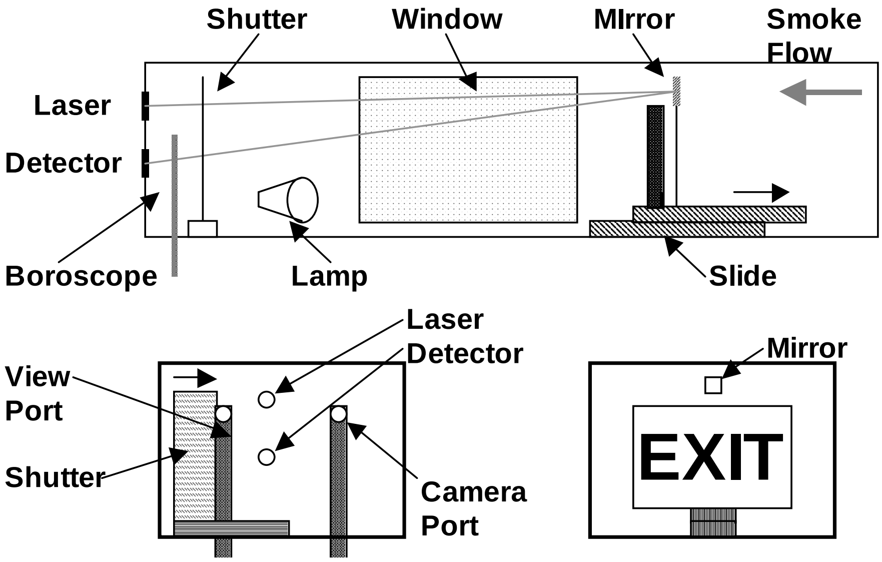

Figure 1. Schematic of the Experimental Setup.

4.30 m. The exit sign scene is viewed through boroscopes that extends into the duct at the far end. One boroscope is reserved for a CCD camera and one is used for human observation. The boroscopes provide a wide-angle view with a magnification of 0.20X. The distance from the boroscope viewing port to the exit sign is 1.92 m, thus the sign appears to be 9.6 m from the viewer. A 150 W incandescent lamp was placed slightly forward of the boroscopes to illuminate the exit sign with external lighting. Room lights were turned off during testing to reduce the ambient light entering the test section windows to a negligible amount. In addition, laser light extinction measurements were taken when the exit sign and external lighting were extinguished. The sign was an internally illuminated exit sign 31 cm by 19 cm with a red colored semi-transparent insert (i.e., red-lettered sign). Letter widths were approximately 20 mm, and the sign contained an11w incandescent bulb.

Images were taken with a 1/3 inch type black and white CCD camera module with a manually adjusted gain setting (the gain setting remained the same for all tests shown here.) One boroscope was coupled to a video zoom lens attached to the CCD camera module. The gain was set such that the brightest pixel intensity was less than the maximum for the brightest (externally-lit) scene. The dynamic range of the CCD camera is such that the background details are not apparent unless the exit sign is over-exposed. Images were acquired with an image acquisition card once per second.

Three different types of smoke: propene soot, wood smolder smoke, and cotton wick smoke were produced for the tests, in addition, ISO Fine test dust was also used to obscure the exit sign. Details on the properties of these smokes and dust are available in another paper in these proceedings [6].

Results and Analysis

The laser transmittance data was used to compute the average extinction coefficient over the viewing path length. The extinction path length of 4.30 m was used to compute the extinction coefficient (k, m^{-1}). The standard uncertainty in the extinction coefficient is estimated as 2% of the value up to 1.0 m^{-1} [5]. Random fluctuations due to varying smoke concentration along the path length are larger than the uncertainty. An apparent extinction coefficient (k_a) was computed using the apparent distance from the sign to the viewing location and the equality below.

$$Ln(I/I_0) = k(1.92) = ka(9.60) \quad (1)$$

The apparent extinction coefficient is the value that would yield the same light transmittance over a path length equal to the apparent sign distance; it is equivalent to the observed extinction coefficient times the boroscope magnification value (0.20). Values of extinction coefficients at alarm activation typically range from 0.03 m^{-1} to 0.1 m^{-1} (1%/ft to 4 %/ft) for cotton smolder smoke.

The CCD image consists of pixels of varying levels of brightness over a range spanning 0 to 255 (8 bit). Brightness is a relative measure proportional the luminance or intensity of the visible radiant energy from the sign. For the purposes here, pixel brightness is considered to be a measure of normalized (non-dimensional) luminance. Thus, contrast measurements may be computed from the pixel brightness values. Three metrics were used to characterize the image change under smoke conditions. First, the average pixel brightness for a region of interest, defined here as the area covering the exit sign, the Weber contrast, and the Michelson contrast. The Weber contrast (C_w) is typically used to characterize contrast between an object and a uniform background, and it is defined as:

$$C_w = L_o / L_b - 1 \qquad (2)$$

Where L_o and L_b are the object and background brightness respectively. Here the object was the illuminated sign letters and the background was the non-illuminated portion of the sign. The Michelson contrast is typically used to characterize periodic variations in luminousity, and it is defined as:

$$C_m = (L_{max} - L_{min}) / (L_{max} + L_{min}) \qquad (3)$$

Where L_{max} is the mean pixel brightness of the letters and L_{min} is the mean pixel brightness of the surrounding sign area.

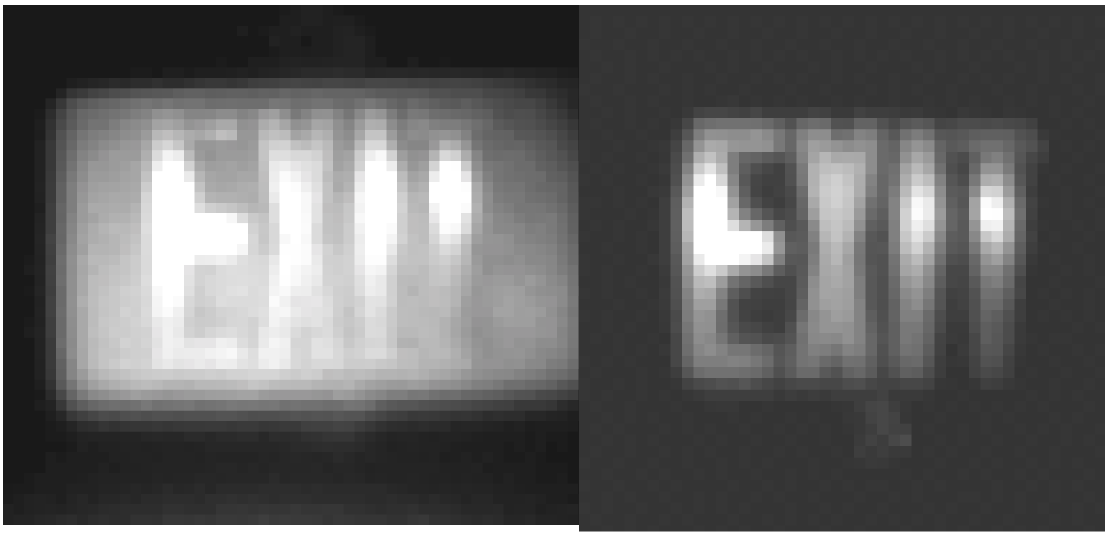

Figure 2. No smoke sign images with and without ambient lighting.

Figure 2 shows the two images of the sign in clear conditions with and without external lighting. The sign letter width in on the order of 4 pixels. The non-uniform letter intensities were caused by uneven illumination related to the location of the lamp inside the sign.

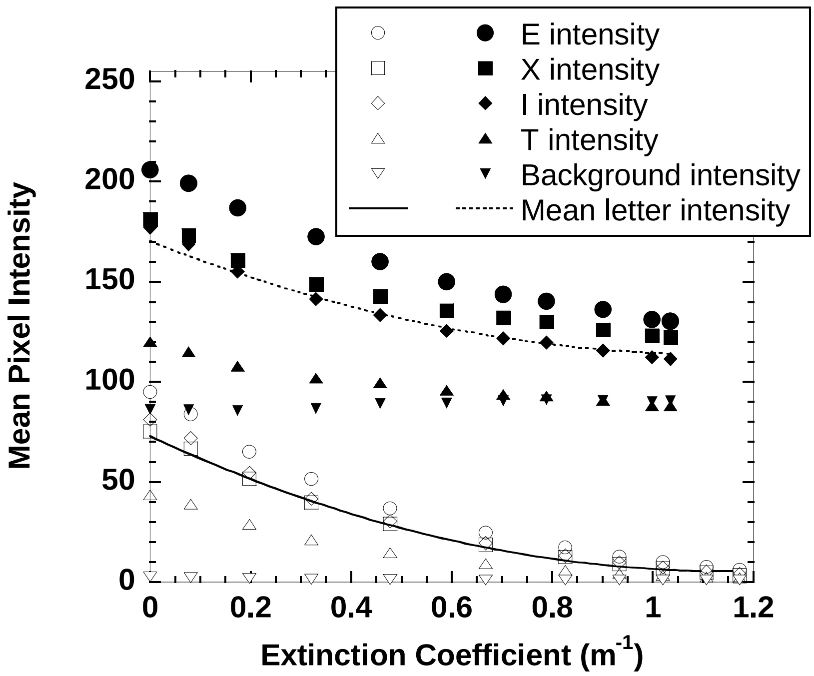

Figure 3. Mean pixel intensity for individual letters and background for wood smoke obscuration. Open symbols – no ambient lighting, closed symbols – ambient lighting.

Figure 3 shows the mean pixel intensities of each letter and the background for two tests, with and without external lighting, and wood smoke obscuration. In clear conditions, the variation in the mean letter intensity was 75% with external lighting and over 100% without external lighting. Without external lighting, the mean background intensity was about 3.0 to start, and decreased as the smoke extinction increases. With ambient lighting, the background intensity actually rose slightly as the smoke extinction increased due to the scattered ambient light. The mean letter intensities are given by the smooth curve that connects the arithmetic mean of the individual letter values at different extinction coefficient values. Figure 4 shows two images with external scene lighting. The left image shows the clear conditions and right image shows the luminous veil produced by wood smolder smoke light scattering at an extinction coefficient of 1.0 m^{-1}. The initial dark boundary surrounding the sign plus the illuminated and non-illuminated portions of the sign approach the same luminance.

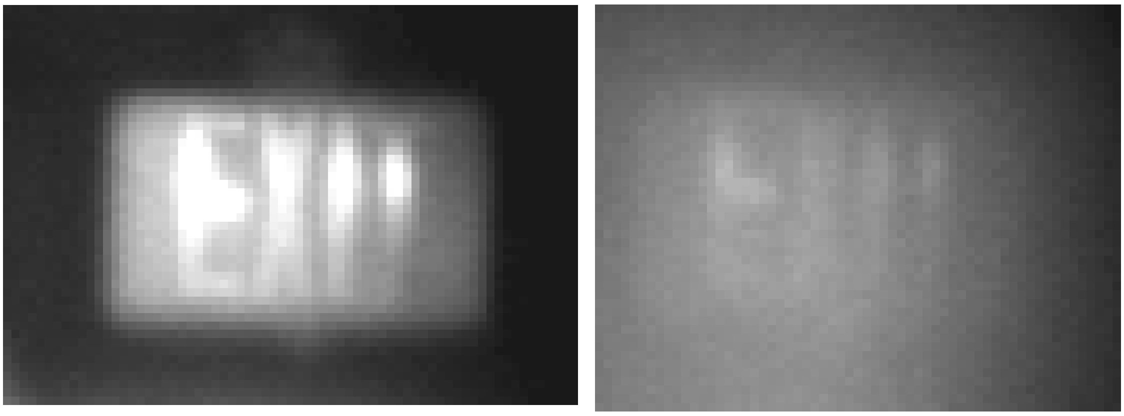

Figure 4. Externally illuminated sign in clear conditions (left image) and in wood smoke with an extinction coefficient of 1.0 m^{-1} (right image).

Figure 5 shows the mean pixel intensities for the region consisting of the sign for all three smokes and ISO test dust. The externally illuminated sign had an initial mean pixel intensity of about 120 units, without external illumination the initial mean pixel intensity was about 35 units. For the case without external illumination, as the extinction coefficient increased the decrease in the mean pixel intensity drops off more rapidly than transmittance expected from an extinction meter (eq. 1) which is represented here as a curve with an initial value of 35. This was due to the large non-illuminated area of the sign, which factored into the average. The results for the externally illuminated sign show that dust, wood, and wick smolder smokes are similar, with an initial drop in the mean pixel intensity followed by a flattening out due to the luminous veil. The mean pixel intensities in soot smoke, on the other hand, continued to drop as the extinction coefficient increased. Soot scatters much less light than the smolder smokes or ISO dust at any given extinction value, where light absorption is the main mechanism for extinction. In terms of smoke detection, a marked decrease in pixel intensity at an extinction coefficient of 0.1 m^{-1} was observed. For this scene that appears to be 5 m away, this yielded an apparent extinction coefficient of 0.02 m^{-1} which is sufficiently sensitive for smoke detection. The only caveat is that the smoke must fill the path between the camera and the sign.

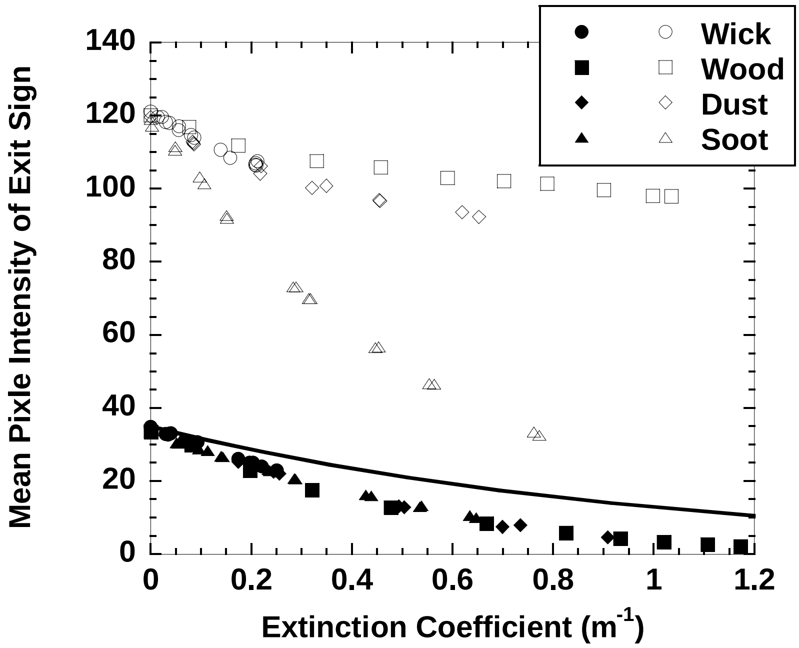

Figure 5. Mean pixel intensity of the exit sign for all smoke and dust. Open symbols –ambient lighting, closed symbols – no ambient lighting. Curve represents light transmission extinction meter results.

Figure 6 shows the results of the contrast calculations for the cases with no external illumination. The Weber contrast for all three smokes and ISO dust were similar and showed a decline with increasing extinction coefficient. The Michelson contrasts were also similar for all three smokes and the ISO dust, remaining relatively flat up to about 0.6 m^{-1}, then decreasing. The observed Weber contrast over the entire extinction coefficient range, and the Michelson contrast up to 0.6 m^{-1} can both be explained by the fact that the mean letter intensity decreased while the background remained consistently low. The observation that the Michelson contrast rolls off above 0.6 m^{-1} was an artifact caused by the constraint that the mean pixel intensity of the background was not allowed to drop below 1.

Figure 7 shows the results of the contrast calculations for the cases with external illumination. The Weber contrast for the two smolder smokes and ISO dust showed a similar rate of decline with increasing extinction coefficient, while the Weber contrast trend for soot showed a slower rate of decline. The Michelson contrast trend for the

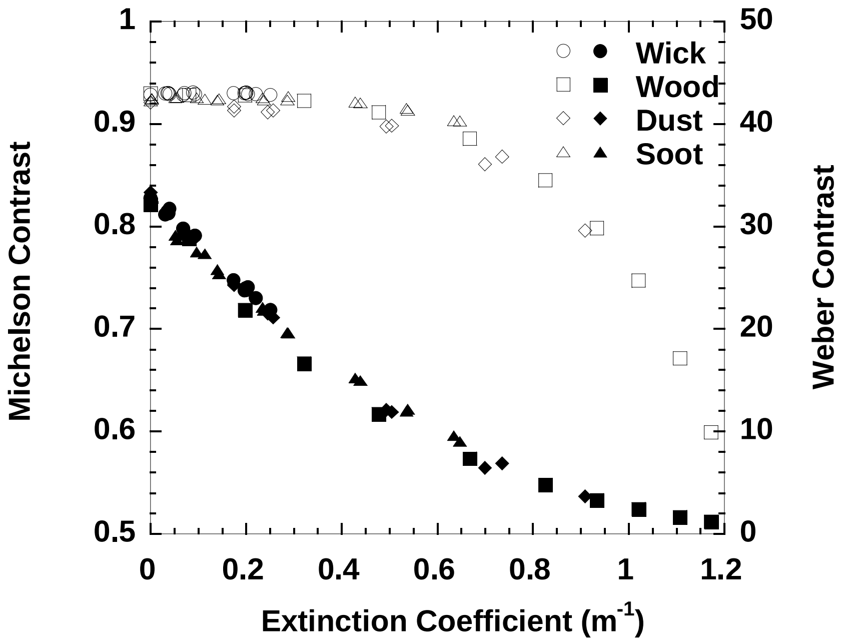

Figure 6. Contrast measurements for experiments without external lighting. Open symbols – Michelson contrast, closed symbols – Weber contrast.

two smolder smokes and ISO were similar and continued to drop as the extinction coefficient increased. For the smolder smokes and ISO dust, both contrast measures continued to decline as the extinction coefficient increased, while the mean pixel intensities of the sign were observed to decline at a much slower rate due to the luminous veil. Michelson contrast trend for soot was markedly different. It was observed to increase from the initial clean air value. This increase in contrast apparently was due to a preferential reduction in the sign background intensity due to reduction of light reflecting off the sign relative to the reduction in the illuminated letter intensities.

Conclusions

(1) Pixel intensity measurements can be used to detect the presence of obscuring aerosols including fire smokes.

(2) Weber contrast measurements can indicate visibility degradation in cases with and without external illumination.

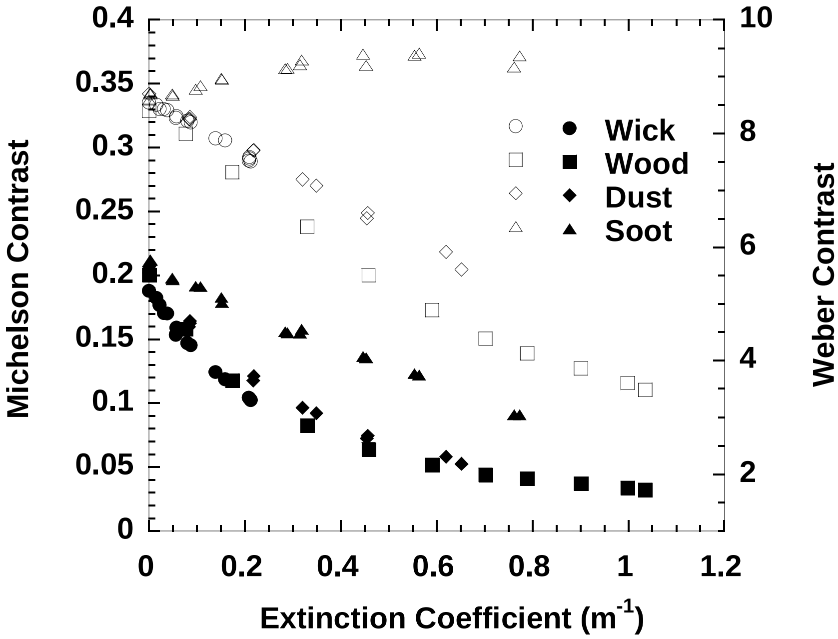

Figure 7. Contrast measurements for experiments with external lighting. Open symbols – Michelson contrast, closed symbols – Weber contrast.

(3) Together, the Michelson and Weber contrast measurements with external illumination can distinguish black soot smoke from smolder smokes and dust.

References

[1] Wieser, D., and Brupbacher, T., "Smoke Detection in Tunnels Using Video Images," AUBE '01, Proceeding, Gaithersburg, MD, Grosshandler, W., Ed., 2001.

[2] Jin, T., "Visibility Through Fire Smoke," J. of Fire and Flam., 135, Vol.9, 1978.

[3] Collins, B., Dahir, M., and Madrzykowski, D., "Evaluation of Exit Signs in Clear and Smoke Conditions," NISTIR 4399, NIST, Gaitherburg, MD, 1990.

[4] Ouellette, M., "Exit Signs in Smoke," Lighting Res. and Tech, Vol. 20, No. 4, 1988.

[5] Cleary, T., Donnelly, M., and Grosshandler, W., "The Fire Emulator/Detector Evaluator" AUBE '01, Proceeding, Gaithersburg, MD, Grosshandler, W., Ed., 2001.

[6] Cleary, T., "Time Resolved Size Distributions of Test Smokes and Nuisance Aerosols," AUBE'04, Proceedings, Duisburg, Germany, Luck, H., Ed. 2004.