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Development of an Elevated Flare Monitor Using Video Image Processing Technique

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Abstract. Elevated flare is widely used in refineries and petrochemical plants to dispose unwanted waste gas. Before releasing to the atmosphere, waste gas is transported to the flare header and combusted with ambient air. Due to the uncontrollable open mode of combustion, emissions of the elevated flare are hard to be diagnosed directly. In this paper, we present a monitoring device using image processing techniques based on FPGA framework. Through a series of tests on a benchmark lab burner and some real flares, it is believed that this device has the potential to monitor both flame and smoke for the elevated flares in a real time manner.

1. Introduction
Elevated flares are used in refineries and petrochemical plants to burn unwanted waste gases generated during upstream process [1]. Unlike a furnace or a boiler where combustion takes place inside a closed space and air supply can be carefully controlled, waste gas in an elevated flare is conveyed to the flare header through a stack and burned directly in the atmosphere. The stack is usually about 80~150 meters high. And the air supply during the combustion is strongly affected by the local wind [2]. The products from the combustion immediately diffuse into the ambient environment. Ideally, most of the hydrocarbons in the waste gas should be completely burned into CO₂ and H₂O before releasing to the environment [3]. However, this open combustion mode makes it very hard to control the emissions such as VOCs and smoke especially under emergency conditions [4].

In a typical petrochemical plant, the operating condition of the elevated flares should be monitored through CCTV cameras on a 24x7 basis [5]. Based on the video images, field workers in the control room can decide whether the flares are operating normally. If smoke is generated during the combustion, steam valve aperture is often manually adjusted to suppress the smoke. However, due to the uncertainty which may be caused by the daylight condition or the harsh weather, this kind of observation is usually not reliable and may sometimes lead to overuse of steam [6].

Several devices have been proposed to monitor and control the flare operation automatically [7-9]. An example is the infrared sensor introduced by LumaSense [10]. By computing the radiation intensities of specific infrared wavelengths, this device can predict the smoke emission level and output a signal to control the steam valve aperture accordingly. However, this sensor cannot show the flame image and is said often generating false signals. In recent years, techniques based on image processing have become more and more popular. Rodrigues et al. proposed a prototype monitoring system using image processing based on visible color video camera and suggested that their device has the potential to analyze the flare under harsh conditions [11]. Zeng et al. invented a device using hyperspectral midwave infrared imager [12]. It is shown that this device can not only show the combustion efficiency distribution but also compute an index to indicate the smoke level. In this paper,
we present a monitoring device that can recognize the flame and smoke simultaneously based on visible light images.

2. System of the monitoring device
As shown in Figure 1, our monitoring device is mainly composed of the following parts: a 12-36 mm zoom lens, a visible CMOS image sensor with a 1/4” size and a 5-Megapixel resolution, a FPGA board for data processing and a LCD screen for display. The adjustable shading tube in the front is used to block the scattering light from the background. The 7-inch LCD screen is connected to the FPGA board and mounted at the back of the module to better view the video image, based on which the lens and control parameters can be adjusted accordingly. The device is powered by a battery embedded within the module and can be charged and powered by 220V AC through cable.

![Figure 1. Flare monitor module](image)

The schematic of the onsite device setup is shown in Figure 2. Depending on the background light condition and the stack height, the flare monitor can be installed within 100 meters to 500 meters. For real flare testing in the field, a mounting tripod is used to adjust the field of view and the aiming angle. And to reduce the interference from the background scattering light, one should avoid aiming the device directly to the sun.
3. Image processing techniques
Hydrocarbon flames generated by the waste gas combustion usually yield colors of yellow and red. If incomplete combustion happens, soot aggregation may lead to smoke emission, showing black or gray color in the video recording. Therefore, color characteristic is firstly used to mark the suspected pixels which might represent flame and smoke.

Turbulent motion is the second characteristic of the flame and smoke. Affected by the momentum of air and flare gas, smoke generated by the combustion often diffuses with the wind very quickly. Frame differential method is applied to identify the smoke and track its motion.

3.1. Flame recognition
To reduce computation complexity, color information is directly drawn from the RGB color space. Pixels are marked as flame when they meet the following three conditions:

\[
\begin{align*}
R(x, y) &\geq \tau_R \\
G(x, y) &\geq \tau_G \\
B(x, y) &\geq \tau_B
\end{align*}
\]

\[
\begin{align*}
R(x, y) &\geq B(x, y) \\
G(x, y) &\geq B(x, y)
\end{align*}
\]

if \( \tau_R \geq 250 \), \( R(x, y)/(R(x, y) + G(x, y) + B(x, y)) \leq \theta \) (3)

Here, \((x, y)\) stands for the two dimensional coordinate of the pixel. In the above equation, threshold values \( \tau_R = 180 \) and \( \tau_G = 180 \). Threshold value \( \tau_R \) ranges from 200 to 240, for cases with high reflections from the background, \( \tau_R \) can be raised as high as 250. And \( \theta \) stands for the ratio of the red color intensity and the sum of RGB intensities and the value is around 0.3 to 0.4.

3.2. Smoke recognition
Smoke generated during the combustion of the waste gas is a result of soot aggregation. When smoke particles diffuse away from the combustion zone, they will be cooled down by the ambient temperature, showing dark to grayish color. The smoke particle have similar values in all the RGB channels, i.e.
\begin{align*}
|R(x, y) - G(x, y)| < \tau \\
|R(x, y) - B(x, y)| < \tau \\
|G(x, y) - B(x, y)| < \tau \\
\frac{1}{3}(R(x, y) + G(x, y) + B(x, y)) < \tau_{\text{Gray}}
\end{align*}

where \( \tau \) is the threshold value ranging from 10 to 20 and \( \tau_{\text{Gray}} \) from 120 to 150.

Nonetheless, background objects such as woods, shadows or clouds may also satisfy the above standard leading to false recognitions. To differentiate the smoke particles with the background, frame difference method is applied to capture the motion characteristics, i.e.

\begin{equation}
FD_t(x, y) = \begin{cases} 
1 & \text{if } |F_t(x, y) - F_{t-1}(x, y)| \geq L \\
0 & \text{if } |F_t(x, y) - F_{t-1}(x, y)| < L
\end{cases}
\end{equation}

Here, \( L \) is the threshold value for the frame difference, ranging from 0.05 to 0.1. \( F_t(x, y) \) and \( F_{t-1}(x, y) \) stand for the pixel values of the current frame and the previous frame at location \((x, y)\), respectively. Through Equation (5), pixels with noticeable motion will be marked with value 1 while the stationary background pixels marked with value 0. Finally, If the pixel value at \((x, y)\) satisfies both of the conditions of Equation (4) and (5), it is then recognized as a smoke pixel.

4. Results and discussion

4.1. Algorithm verification

The detecting algorithm is first tested on Matlab environment using video samples recorded from experiments. Figure 3 shows the flame and smoke recognition of an outdoor experiment on a cloudy day while Figure 4 shows the recognition of an indoor experiment where a white board is used to mimic the background. The left images in both figures are the original video images. The images in the middle show flame recognition covered with red color. The ones on the right are binary images where smoke pixels are marked by the white dots.

![Figure 3. Fire and smoke recognition at different time (outdoor video)](image-url)
Figure 4. Fire and smoke recognition at different time (indoor video)

As shown in Figure 3 and 4, variations of the shape and size of the flames are vividly captured. One need to carefully adjust the threshold values to avoid false recognitions coming from strong reflections on the cloud or the white board. On the other hand, successful smoke capturing is to some extent limited within the region near the flame (see Figure 4). This is because those particles diffused away from the flame have similar gray-scale values with the background, making the motion tracking insensitive.

4.2. Benchmark test of the lab burner

The algorithm in Section 3 is then programmed in Verilog and burned into the FPGA framework. Tests of the device are carried out on a lab burner. As shown in Figure 5, the burner is about 20 cm high and has a diameter of 1 cm. During the experiment, propane or ethylene is used as the fuel which is fed into the burner through the tube from the bottom. The flame size can be modulated by adjusting the fuel flow rate. Compressed air can be fed in through another tube to create a premixed air-fuel mixture. By adjusting the air flow rate, the amount of smoke is modulated.
Figure 5 shows the benchmark test performed outdoor during the daytime. The burner is elevated at a height of 1.8 m while the monitoring device is located about 3 m away from the burner with an aiming angle of around 30°. In a real petrochemical plant, flares may be surrounded by other buildings or objects. In this test, several other burners are placed nearby to mimic the dirty background.

Figure 6 shows the fire and smoke recognition of the lab burner benchmark test. Images on the left is the original video image recorded by the monitor. Images on the right shows the fire and smoke recognition, where fire is marked by the red color and smoke by the green color. The shape of the fire and the motion of the smoke particles are well identified.

4.3. Field test of elevated flares
Testing of the device was then performed on real flares. Figure 7 shows the testing images of a hydrogen-rich flare carried out on a sunny day during the afternoon. The image on the right shows that the flame is vividly captured. Since hydrogen-rich flares burns mainly hydrogen and light-weight hydrocarbons, no smoke is monitored.
As shown in Figure 8, test of the device was carried out on a steam assisted flare on a rainy day during the morning. Two flare headers are observed in this case. One of the flare is burning waste gas in low flow rate while the other is only burning the pilot gas. The shape and movement of the two flames are vividly captured, as shown by the red color on the LCD screen. A scarce amount of smoke is also monitored as shown by the green dots near the trailing region of the bigger flame. However, the green dots on the flare tip is a false recognition caused by the twinkling reflections on the flare header.

5. Conclusion
A flare monitoring device has been built based on imaging processing techniques within the FPGA framework. The detecting algorithm has been verified using videos recorded from experiments. The results have shown that the algorithm can capture the flame region quite accurately and can identify most of the smoke particles. A series of tests of the device have also been carried out on lab burners and real flares under different weather and daylight conditions. The results have shown that flame and
Smoke can be simultaneously monitored in a real-time manner. The device functions well within 100 to 500 meters from the flare stack and can effectively capture the flame. In the future, in order to be deployed as an automatic monitoring and control unit for real flares, the device performance needs to be improved in the following aspects:

1) Algorithms for smoke detection will be improved to identify the smoke particles with a similar gray-scale value with the background.
2) Higher resolution visible image sensor will be used to capture better images during the night time.
3) Infrared sensor will be integrated to identify the product constitutions under harsh environment such as fog and heavy rain.
4) Based on the flame and smoke information, an automatic control system will be added in the monitoring device to assist the smoke suppression.

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References
[1] Baukal C E Jr. 2014 The John Zink Hamworthy combustion handbook 2nd edition: Volume 3 – Applications. CRC Press 251-297
[2] Castiñeira D and Edgar T F 2008 CFD for simulation of crosswind on the efficiency of high momentum jet turbulent combustion flames. J. Environ. Eng. 134(7) 561-71
[3] Keller M R and Noble R K 1983 RACT for VOC A burning issue, Pollution Engineering
[4] Stone D K, Lynch S K and et al. 1992 Flares. Part I: Flaring technologies for controlling VOC-containing waste streams. J. Air Waste Manage 42(3) 333-340
[5] Venkoparao V G, Hota R N and et al. 2009 Flare monitoring for petroleum refineries. 4th IEEE Conference on Industrial Electronics and Applications. 3022-3027
[6] Singh K D, Gangadharan P, and et al. 2014 Parametric study of ethylene flare operations using numerical simulation. Engineering Applications of Computational Fluid Mechanics 8(2) 211-228
[7] Okamoto H and Nakauchi S 1980 Flare monitoring apparatus, US Patent 4,233,956
[8] Dibiano R, Autenrieth K and Hales G 1985 Control of smoke emissions from a flare stack, US Patent 4,505,668
[9] Rao V S, Venkoparao V G and et al. 2009 Flare monitoring, US Patent 7,876,229 B2
[10] LumaSense Technologies, Inc. 2015 E2T QUASAR 8100 SM Operation Manual
[11] Rodrigues S J and Yan Y 2011 Application of digital imaging techniques to flare monitoring. J. Physics: Conf. Ser. 307 012048
[12] Zeng Y, Morris J and Dombrowski M 2016 Validation of a new method for measuring and continuously monitoring the efficiency of industrial flares. J. Air Waste Manage 66(1) 76-86