Flame monitoring with an AER color vision sensor

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Abstract—We present a new method to sense NIR (Near Infrared Radiation) with an asynchronous pixel event AER (Address Event Representation) color vision sensor. The sensor’s asynchronous output data flow can be processed by a computer to monitor oscillations of NIR illumination levels. Such variations can be indicators for fires or flames. The new sensor is an alternative to high-speed CMOS cameras with NIR filters as front-end for flame detection and characterization methods. Our sensor maintains a high temporal resolution and low latency for regions that are bright in the NIR spectrum, e.g. flames and hot-spots, at an overall low (scene dependent) data rate and power consumption. This makes it specially suitable for Wireless Sensor Networks (WSNs). A dedicated real-time Java interface was programmed to process the sensor outputs. In this paper, we describe the algorithm for sensing NIR intensity and describe experiments that show oscillations of NIR levels of a flame.

I. INTRODUCTION

Early fire detection is crucial. Every year thousands of forests are burnt in Mediterranean countries like Spain, Portugal, Italy or Greece. The restoration cost is quite high, and sometimes, not affordable (between 1000€ and 5000€ per hectare [1]). Fire and flame detection is also quite important in warehouses and industrial environments.

Infrared cameras can easily detect fire and hot spots. Unfortunately, such detectors are expensive, difficult to handle, and fragile [1]. Therefore, they are not suitable for surveillance networks where a considerable number of them are required. An alternative to infrared detectors are CMOS cameras with Near Infrared Radiation (NIR) filters, as e.g. reported in [2]–[5], to name but a few. Silicon photodiodes can transduce Near Infrared Radiation (NIR) light into current up to a wavelength of approximately 1100nm, and a NIR filter centered at typically 950nm with a bandwidth from [750,1100]nm turns them into NIR imagers. Their output frame sequence can then be processed by dedicated tailored frame-based algorithms to detect either fire, flames or smoke (using NIR LEDs).

Frame-based vision sensors have inherent limitations, i.e. they are continuously sending redundant information, they have high power consumption, and their response speed and temporal resolution is limited by the by frame rate. On the contrary, bio-inspired AER (Address Event Representation) vision sensors are inherently faster at a lower total data rate since the rate is individually adapted for each pixel, and have consequently lower power consumption, [6]–[10]. Their event-based outputs can also be conveyed easily by radio signals [11]. Thus, they have huge potential for distributed fire surveillance systems.

In this paper, we present a novel method to monitor temporal variations of NIR, that can indicate the presence of flames, using a color bio-inspired vision sensor [12]. The sensor outputs are processed by a real-time algorithm that extracts NIR levels, rather than using a filter. The simple sensor provides high temporal resolution of the actual flame being monitored without actually being an expensive high speed sensor: bright pixels (i.e. the flame) are updated much more often than the background pixels. Typically, we achieve a latency response time below milliseconds when pixels are exposed to flames. This is equivalent to a frame-based system with a frame rate higher than 1k frames/s.

The paper is organized as follows: In section II, we explain how flames are detected by operating a CMOS sensor in the NIR band. Section III, describes the sensor. Section IV describes the NIR detection algorithm. Finally, section V shows experimental results.

II. FIRE DETECTION IN THE NIR BAND

A CMOS camera without filters detects radiation beyond the visual spectrum, i.e. Ultra Violet ([250,390]nm), visible ([390,750]nm), and NIR ([750,1100]nm). Hot spots, fire or flames can be detected with a CMOS sensor with a NIR filter [3], [13] (where hot spots need to be above 350°C). Smoke detection is possible too when employing NIR sources (e.g. NIR LEDs).

In our particular case, we will exploit the fast response time and good temporal resolution of our AER vision sensors [12] to monitor oscillations of NIR levels provoked by the presence of flickering flames [4], [14] without using NIR filters. Flames have frequency components within the interval [0,250]Hz. Their oscillatory characteristics are important to determine the flame structure and stability [14]. In the next sections, we will describe how to process our sensor’s output to separate NIR emissions from UV and visible radiation.

III. AER COLOR OCTOPUS RETINA

The sensor pixels [12] employ three different stacked photodiodes at different depths. Each photodiode has different sensitivity to different light wavelengths. The top one is more sensitive to blue light, the next one is more sensitive to green light, and the bottom one can detect red and NIR light. The top most photo current $I_B$, and the sums of the top and middle currents $I_{BG}$, and middle and bottom currents $I_{GR}$ are connected to a integrate and fire neurons that fires with
After calculating the energies associated to each photodiode, the pixel NIR levels are calculated by comparing $E_R$ (which contains energy from the early infrared band) to $E_G$ (which also contains energy from the visual red band):

$$IR = \frac{E_R^2}{E_G}$$  \hspace{1cm} (1)

$IR$ is then the ratio between $E_R$ and $E_G$ multiplied by $E_R$, i.e. a number that is dependent on absolute illumination as well as the relative spectral content of NIR versus visual light. For displaying $IR$ on the Java interface, we bounded it by [0, 1] between black and fully saturated red. Flames cause flickering and oscillations of the NIR energy, that can be monitored, as it will be shown in the next section.

### IV. NIR detection algorithm

Post processing described in detail in [12] estimates the relative energies in the absorption spectra of the three photodiodes, $E_B$, $E_G$, and $E_R$. Keep in mind that these absorption spectra are much more broad-band than real RGB spectra. Also, the unit of these energies is arbitrary only allowing relative comparisons (over time and location) within the same sensor as the absolute intensity hitting the pixels could not be measured with any accuracy. The energies are updated pixel wise with every incoming event.

#### A. Near Infrared Detection

To test the performance of the proposed NIR detection algorithm, a group of pixels was stimulated with a monochromator capable of emitting light in the range within $[350, 850] nm$. Fig. 2 shows their relative response for each wavelength. Unfortunately, the monochromator cannot emit light above $850 nm$. However, we were able to qualitatively validate the NIR detection above $850 nm$ with a TV-remote emitting light at $940 nm$.

#### B. Flame Monitoring

Flame monitoring was tested in two different environments: An office, with artificial illumination of approximately $600 lux$, and outdoors, with natural illumination of $1500 lux$. The sensor was exposed to flames at a distance of $0.5 m$ emitted with a gas lighter. We used a $4 mm$ CS-mount objective for the test. Results are not very sensitive to the distance between the flame and the sensor, as long as the flame is properly focused and a reasonable number of pixels are exposed to NIR variations provoked by the flame. Fig. 3 shows a typical image displayed by the Java interface when a flame is observed.
and Fig. 4 displays typical pixel representation values after taking a snapshot with a flame. Different flame combustion regions [14] can be differentiated.

and Fig. 4 displays typical pixel representation values after taking a snapshot with a flame. Different flame combustion regions [14] can be differentiated. Fig. 5 shows the NIR global pixel activity (i.e. all pixels summed) with outdoors and indoors illumination. Flames provoke an increase of the global event activity. They also provoke temporal oscillations of event activity. With indoors illumination the background NIR level, \( \sum \sum IR_{i,j} \), was 0.18. With a flame in the scene, the average value was 2.12. With outdoors illumination, the average NIR background level was 4.48. With a flame, this value was increased to 5.77. In the flame, the asynchronous pixel update rates where in the range of 1-8 kilo-events per second (kevents/s) indoors and 5-20 kevents/s outdoors. To compute an fast Fourier transform, we (sub-)sampled the resulting data stream at an arbitrary \( T = 0.005s \), to be able to represent frequencies of up to 100Hz. With an actual pixel update rate in the region of interest of more than 1kHz, however, we could also represent higher frequencies. Fig. 6 shows the relative power-spectral-density (PSD) distribution of the sum of all pixels in the observed scene, i.e. the PSD of the flicker signals of Fig. 5 provoked by flames in indoor and outdoors environments. Flames main frequency components are distributed mainly between DC and 50Hz. The frequency components distribution is very similar to the one reported in [14], where the authors employed a high speed CCD camera. Thus, our sensor and NIR extraction algorithm can be a cheap
alternative front end for flame detection and studies of flame structure and stability. A pixel event rate in the order of kevents/s would be an equivalent speed to the one that we can achieve with a frame-based high-speed camera with a frame rate higher than 1 kframe/s.

As future work, the algorithm could be implemented in a FPGA attached to the sensor. We could also build on-chip the digital circuitry necessary to process the data lowering the cost. We could also test the performance and reliability of the system to detect flames, hot spots and smoke.

VI. CONCLUSIONS

We have employed a bio-inspired color AER vision sensor to observe flickering and oscillations of NIR radiation of a flame and have qualitatively compared it to front ends based on high speed CMOS cameras with NIR filters. Due to pixel individual asynchronous update rates the sensor provides high temporal resolution on a (scene dependent) overall data rate that is small when considering the temporal resolution in the region of interest. Experiments were conducted both indoors and outdoors, demonstrating the sensor’s capability to operate robustly also with relatively large NIR background activity.

We see great potential for these type of sensors front ends for low-cost distributed wireless systems, for low-latency accurate localization of fire sources.

REFERENCES