10.21611/qirt.2019.014

Infrared Vision System for Spectral Monitoring of Dynamic Phenomena at 1000 fps: application to combustion

by M. Strojnik, B. Bravo-Medina*

** Optics Research Center, Apdo. Postal 1-948, 37000 Leon, Gto., Mexico; mstrojnik@gmail.com*

Abstract

For the last 15 years we have been studying initiation and propagation of rapidly evolving processes in IR and developing the instruments to capture the essential features of combustion phenomena. We present an IR optical experimental setup to capture two spectral images of the same scene. We apply this technique to flame analysis in the mid-IR to determine the combustion efficiency, as measured by the CO-gas production.

1. Introduction (Arial, 9pt, bold)

We are interested in exploring phenomena in our environment in IR spectral region. Wild fires, and more generally, all combustion processes are examples of natural phenomena that human brain is not capable of capturing and processing due to the rapidity of their evolution [1-3]. Figure 1 illustrates several examples of quasi-static combustion processes, indicating different spatial and spectral features.

Fig. 1: *Examples of quasi-static combustion processes, indicating different spatial and spectral features [4].*

2. Combustion evolution in a controlled environment

Within a stovetop burner, the flame spreads rather rapidly, propagating around full rim within a second. However, it may start at an arbitrary point in time after turn-on due to specific environmental conditions [5]. Figure 2 presents visible and IR images of the ignition process in a gas-stove (produced by Mabe, a Mexican subsidiary of GE), initiated with an electrical spark. Among the challenges of the combustion measurements is the difference between the flame, as observed by a human visual system that detects colors within 0.4 to 0.8 micron visual spectral band, and in IR, where we record the increase in temperature that results as a consequence of the heat generated in combustion.

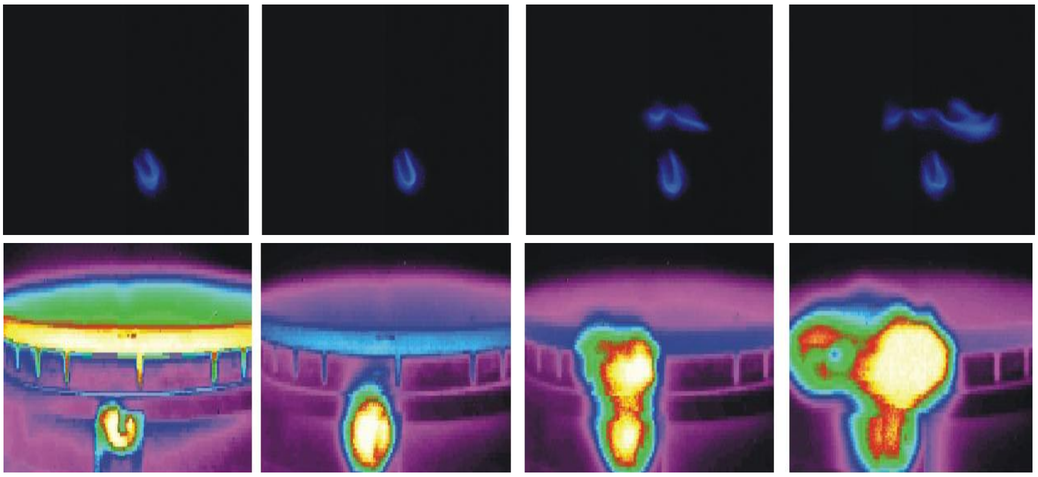

Fig. 2: *Visible and IR images of the ignition process in a stovetop burner (GE), initiated with an electrical spark [6].*

3. Experimental techniques

Two aspects of combustion are particularly challenging for implementing in experimental techniques. The first one is in that combustion is a volume effect. Therefore, the generated radiation interacts with process by providing heat to accelerate it. The calibration presents the second challenge: a comparison with a reference must be accomplished concurrently. Figure 3, left, illustrates the phase measurement through the combustion volume, using a vectorial shearing interferometry, clearly delineating the primary combustion region. On the right, we observe two images of flames in different narrow spectral bands for relative comparison.

10.21611/qirt.2019.014

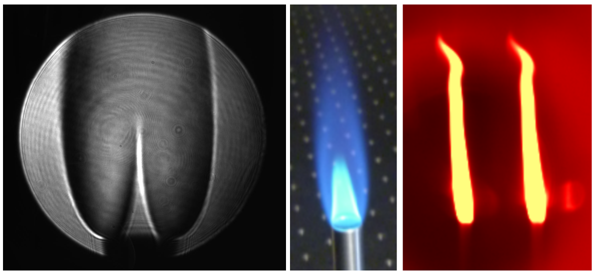

Fig. 3: *Shearing interferometry (left [7]) outlines the primary flame, while spectroscopy identifies gases (right).*

4. Spatio-temporal evolution of flame

The third, and potentially most challenging aspect of combustion measurements is in temporal evolution of the process. Even the stationary flames exhibit the so-called breathing, an oscillatory change in flame volume and intensity with time. In Figure 4, we display the temporal evolution of flame for combustion with low (left) and high (right) oxygenation during 1 second.

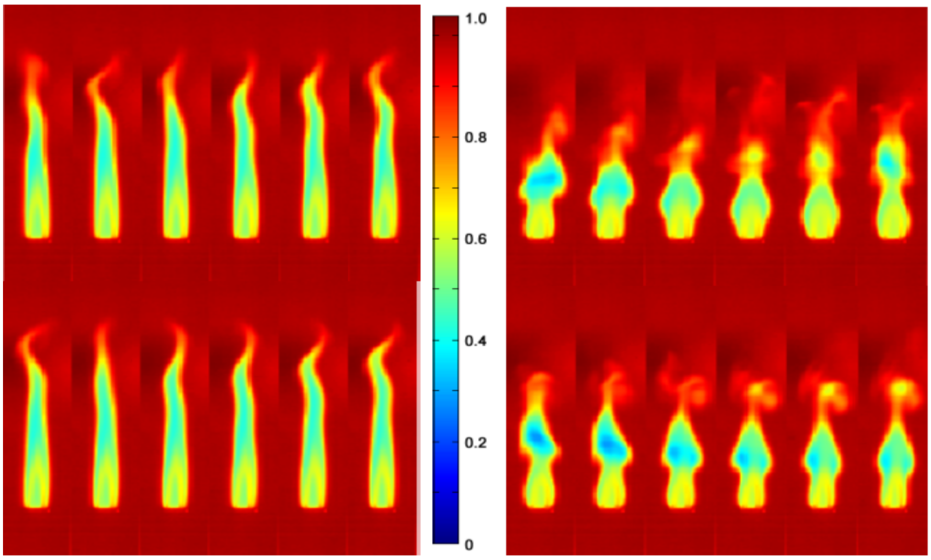

Fig. 4: *Twelve representative images illustrating the relative spatial combustion efficiency during initial 1s. Left panel indicates the case of low oxygenation, right panel that of high oxygenation. The color scale denotes 0 for pure CO (dark blue) and 1 pure CO2 (dark red). Air turbulence forms on top of flame in case of high oxygenation on the right [8].*

REFERENCES

[1] A. Aranda, “Two-wavelength differential thermometry for microscopic extended source,” Inf. Phys. Tech. 49, 205-209 (2006). http://doi.org/10.1016/j.infrared.2006.06.005

[2] M. Strojnik, M. K. Scholl, “Analysis of propagation of complex fire: case of the Yarnell Hill Fire 1,” in Infrared Remote Sensing and Instrumentation XXIII, Proc. SPIE 9608 (2015); https://doi.org/10.1117/12.2191725.

[3] M. Strojnik, M. K. Scholl, “Yarnell propagation dynamics of a mountain fire: case of the yarnell hill fire 2,” in Infrared Remote Sensing and Instrumentation XXIII, Proc. SPIE 9608 (2015). https://doi.org/10.1117/12.2191722.

[4] J. C. Granados, "Flame thermometry," Proc. SPIE 6307, Unconventional Imaging II, 63070L (7 September 2006); http://dx.doi.org/10.1117/12.674938.

[5] M. Strojnik, M. K. Scholl, “Combustion initiation and evolution during the first 400 ms in a gas burner at 10 μm,” Infr. Phys. & Tech. 61 (2013) 42–49; http://dx.doi.org/10.1016/j.infrared.2013.06.001

[6] E. Lopez, "Flame evolution during first second after ignition in a gas stove," Proc. SPIE 7082, Infrared Spaceborne Remote Sensing and Instrumentation XVI, 70820N (3 September 2008); http://dx.doi.org/10.1117/12.797452.

[7] M. Strojnik, "Vectorial shearing interferometry for combustion application," Proc. SPIE 6307, Unconventional Imaging II, 63070I (7 September 2006); http://dx.doi.org/10.1117/12.696587.

[8] M. Strojnik, “High-resolution bispectral imager at 1000 frames per second,” *Optics Express* **23**(19) A1259 (21 Sep 2015); https://doi.org/10.1364/OE.23.0A1259.