IDENTIFICATION OF FLAME CHARACTERISTICS BY COUPLING OF A THERMAL METHOD AND IMAGE PROCESSING

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Summary

I. Context
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I. Context

Wildland fires have a huge impact on 3 main points:

- Environment (Greece 2007: 200,000 affected hectares)
- Economy (Australia 2009: 750 destroyed houses)
- Men (Australia 2009: 200 killed people)

According to the World Health Organization, fires in forests will reach an upper level of risk due to climatic changes.

Necessity to better understand how fires work
I. Context

- Four modeling approaches:
  - Empirical (Rothermel 1972)
  - Cellular automata (Alexandridis et al. 2008)
  - Geometrical (Glasa and Halada 2008)
  - Physical (Séro-Guillaume et al. 2008)

- The main problem of the physical modeling is the high number of entrance parameters ($T_f$, $K_f$, ROS, $\alpha_f$...)

☞ How to get entrance parameters?
I. Context

- The best way to get parameters is real experiments but:
  - Expensive cost
  - Equipment constraints
- Due to those reasons entrance parameters are also obtained at fire tunnel scale or laboratory scale
- Experimental methods to get entrance parameters are classified in two categories:
  - Discrete (thermocouples, threads)
  - Continuous (heat flux sensors, computer vision)
Computer vision techniques have shown promising possibilities for giving fire front positions.

Heat flux sensor method have also shown it efficiency for giving both physical and geometrical parameters but:

- Optimization process on a lot of parameters
- Computational time depends on the number of the entrance parameters
I. Context

The aim of this work is to combine heat flux sensor and computer vision in order to reduce the number of parameters in the optimization process.
II. Heat flux sensor method

- The sensor

[Diagram showing the heat flux sensor components including multiple thermal gauges, transmitting antenna, digitalization box, thermocouples support, insulator, copper plate, glue coat, steel frame, and height 200 mm.]
II. Heat flux sensor method
II. Heat flux sensor method

- Mathematical modeling:
  - Frontal face:
    
    $$\Phi^{th}_{a} (M) = \frac{B}{\pi} \int_{W}^{W} K_f T_f^4 \ln \left( \frac{\sqrt{(y_0 - y_f^F)^2 + X^2} \ l_f + \sqrt{(y_0 - y_f^B)^2 + X^2 + l_f^2}}{\sqrt{(y_0 - y_f^B)^2 + X^2} \ l_f + \sqrt{(y_0 - y_f^F)^2 + X^2 + l_f^2}} \right) dX$$

  - Lateral faces:
    
    $$\Phi^{th}_{l} (M) = \frac{B}{\pi} \int_{y_0 - y_f^F}^{y_0 - y_f^B} K_f T_f^4 \ln \left( \frac{Y \ l_f + \sqrt{Y^2 + W^2 + l_f^2}}{\sqrt{Y^2 + W^2} \ l_f + \sqrt{Y^2 + l_f^2}} \right) dY$$
III. Image processing approach

- Summarized in four steps:
  - Cropping images of the propagation zone from a video recording.
  - Direct Linear Transformation (DLT) to find real fire coordinates from camera fire pixel coordinates.
  - Segmentation of the fire front lines.
  - Computation of the fire front lines positions.
III. Image processing approach

- Segmentation of fire: Ko et al. (2009)
  - RGB probability model
  - Independence of RGB Channels

\[
p_i(x, y) = \frac{1}{\sqrt{2\pi}\sigma_i} \exp\left(\frac{(I_i(x, y) - \mu_i)^2}{2\sigma_i^2}\right), \quad i \in \{R, G, B\}
\]

\[
p(I(x, y)) = p_R(I_R(x, y)) \times p_G(I_G(x, y)) \times p_B(I_B(x, y))
\]

\[
\begin{align*}
&\text{if } p(I(x, y)) > \tau \\
&\text{then: } I(x, y) \text{ is fire-pixel} \\
&\text{else: } I(x, y) \text{ is not fire-pixel}
\end{align*}
\]
IV. Combining the two approaches

- Fire front positions obtained by image processing are as reliable and accurate as those obtained by applying the heat flux method.

- The main idea is to give fire front positions calculated by image processing as fixed parameters for the radiative heat flux approach in order to reduce the number of unknown parameters involved.
IV. Combining the two approaches

The inverse problem considered here can be stated as the following bound constrained minimization problem:

\[
\begin{align*}
\text{minimize} & \quad J(\xi) \\
\text{subject to} & \quad \xi_l \leq \xi \leq \xi_u \\
\text{with} & \quad J(\xi) = \frac{1}{\Phi_{\text{exp}}} \sum_{k=1,2,4} \left( \| \Phi_k^{\text{th}}(\xi) - \Phi_1^{\text{exp}} \| + \| \Phi_k^{\text{th}}(\xi) - \Phi_2^{\text{exp}} \| + \| \Phi_k^{\text{th}}(\xi) - \Phi_4^{\text{exp}} \| \right) \\
\text{with} & \quad \xi = \left( y_{f_1}^k, y_{f_2}^k, \ldots, y_{f_N}^k, l_f, \phi_f \right)
\end{align*}
\]
V. Experimental conditions

- load of 1.2 kg.m$^{-2}$ of straw
- Effective burning area of 2 m$^2$ (2 m x 1 m) with a depth of 0.2 m.
- Video camera (640x480, 30 images/s)
V. Experimental conditions
VI. Results and Discussion
### VI. Results and Discussion

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<tr>
<th></th>
<th>Slope [^{\circ}]</th>
<th>–10</th>
<th>0</th>
<th>+10</th>
<th>+20</th>
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<tbody>
<tr>
<td>Flame length (l_f) [cm]</td>
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<td>53.5</td>
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<tr>
<td>Flame radiative heat flux (\Phi_f) [kW.m(^{-3})]</td>
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<td>7.630</td>
<td>7.624</td>
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<td>Apparent flame temperature (T_f) [K]</td>
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<td>875</td>
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<td>1329</td>
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<tr>
<td>Flame emissivity (\varepsilon_f)</td>
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<td>0.18</td>
<td>0.25</td>
<td>0.27</td>
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<tr>
<td>Mean flame thickness (\delta_f) [cm]</td>
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<td>28.2</td>
<td>27.0</td>
<td>40.8</td>
<td>42.9</td>
</tr>
</tbody>
</table>
VI. Results and Discussion

![Graph showing positions vs. time for different directions and angles.](image)

Legend:
- □ Backward -10°
- ▲ Backward 0°
- ◇ Backward +10°
- ○ Backward +20°
- ■ Forward -10°
- ▲ Forward 0°
- ● Forward +10°
- ● Forward +20°
VI. Results and Discussion

![Graph showing the rate of spread vs slope angle]

- ROS Forward
- ROS Backward

Rate of spread [cm/s] vs Slope angle [°]
VII. Conclusion

- A flame model with mean thermal and radiative properties has been derived from the radiative transfer equation.

- The equations obtained give simple relations to minimize the differences between the theoretical and the experimentally measured radiative heat fluxes.
VII. Conclusion

- Coupling image processing and the wireless heat flux sensor gives results in good agreement with those found in the literature.

- The computational time of the new metrological tool is twice as fast as the one without implementation of the image processing method.
thanks for your attention!