Descending Motion of Vortex Associated with Candle Flame Oscillation: Convective Flow Visualization, Motion Enhancement, and Velocimetry

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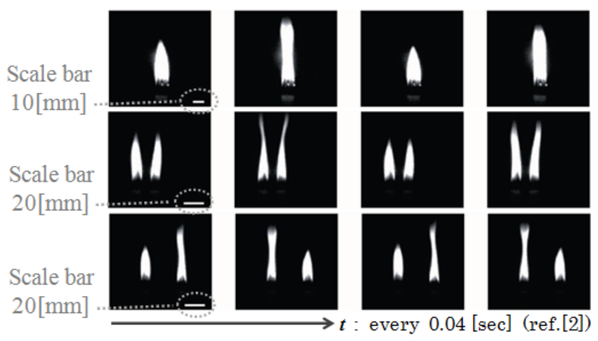
Introduction and purpose



Candle flame oscillation (a single oscillator)

Two candle oscillators coupling (inphase synchronization)

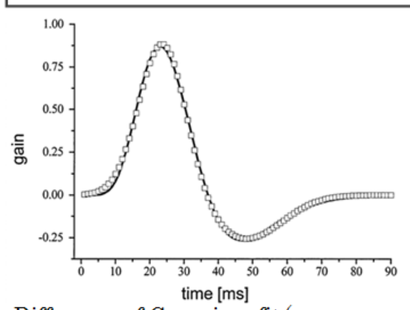
Two candle oscillators coupling (antiphase synchronization)

Purpose

- As one of the simple systems of a nonlinear oscillator, the oscillatory combustion of a set of candles was found by Ishida and Harada (ref.[1]).
- Kitahata et al. (ref.[2]) reported that two candle oscillators can couple with each other, resulting in both inphase and antiphase synchronization depending on the distance between the two candles.
- In candle flame oscillation, we think that convective flow above the candle flame is important, because a kind of vortex was observed above the candle flame by thermography.
- In this report, we developed analysis tools of convective flow above the candle flame.

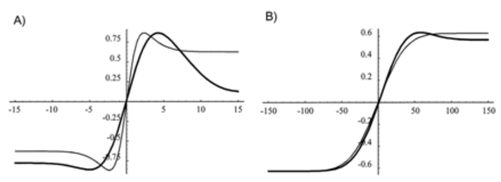
Method

Motion enhancement



Difference-of-Gaussians fit (open squares) to the temporal impulse response function of McKee and Taylor (1984) (continuousline) (ref.[3]).

Pääkkönen & Morgan (ref.[3]) offered an idea based on that the visual response to a briefly flashed image is biphasic. A wave of excitation followed later by a wave of inhibition.



Motion blurring (ref.[3])

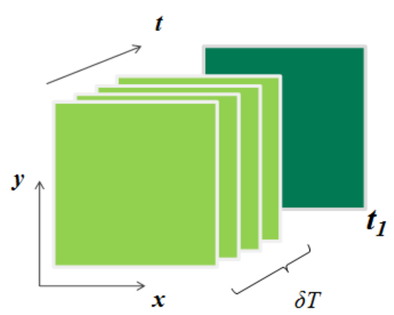
Motion sharpening (ref.[3])

$$f_{tAV}(x,y,t)=\frac{1}{\delta T+1}\sum_{j=-\delta T}^{0} f(x,y,t+j) \quad (1)$$

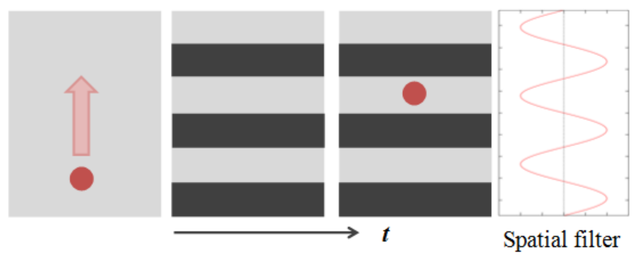
$$f_{tDif}(x,y,t)=\alpha\times\{f(x,y,t)-f_{tAV}(x,y,t)\}+127 \quad (2)$$

(ref.[4])

f: image intensity,
f_{tAV} : locally averaged image sequence,
f_{tDif} : differenced image sequence,
δT: local temporal domain,
α: gain factor



Spatial filtering velocimetry



$$I(x,y,t)=f(x,y,t)\cdot\sin\{\vec{K}\cdot(\vec{r}-\vec{v}_s t)\} \quad (3)$$

f: image intensity, I : filtered image, $\vec{K}$: wave number of spatial filter, $\vec{r}$: position of target pixel, $\vec{v}_s$: translation velocity of spatial filter

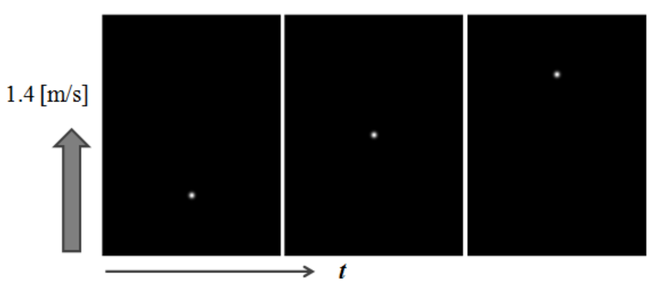
$\left(\ |\vec{K}\ |=\frac{2\pi}{\lambda}\ \right)$

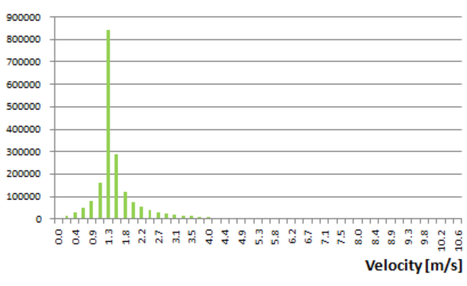
$$A(t,\vec{K})=\sum_x\sum_y I(x,y,t) \quad (4)$$

A : time series data

Spectral analysis

Example

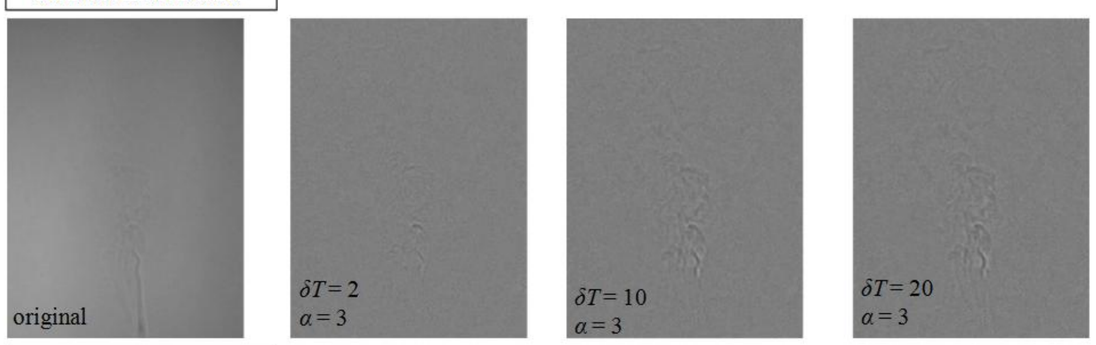




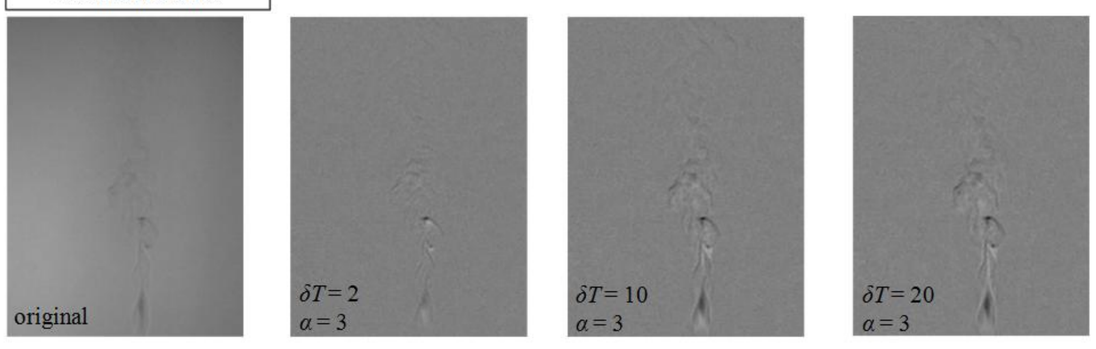
Results

Motion enhancement

Non-oscillation state

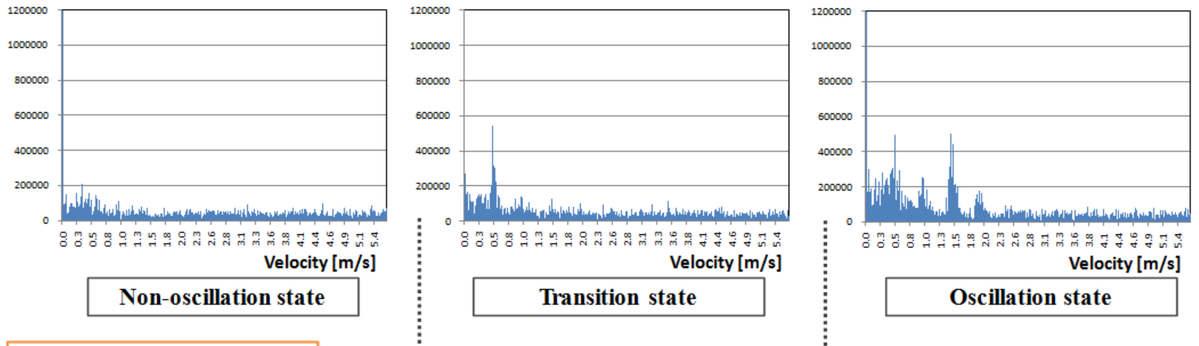


Oscillation state

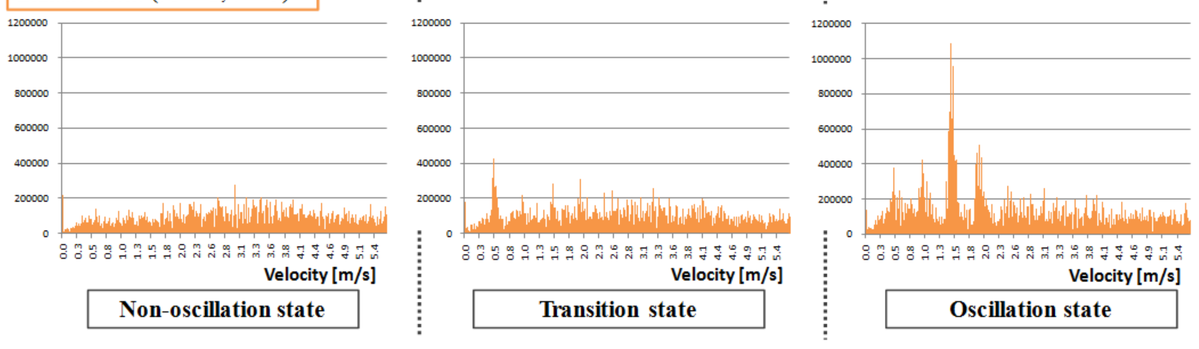


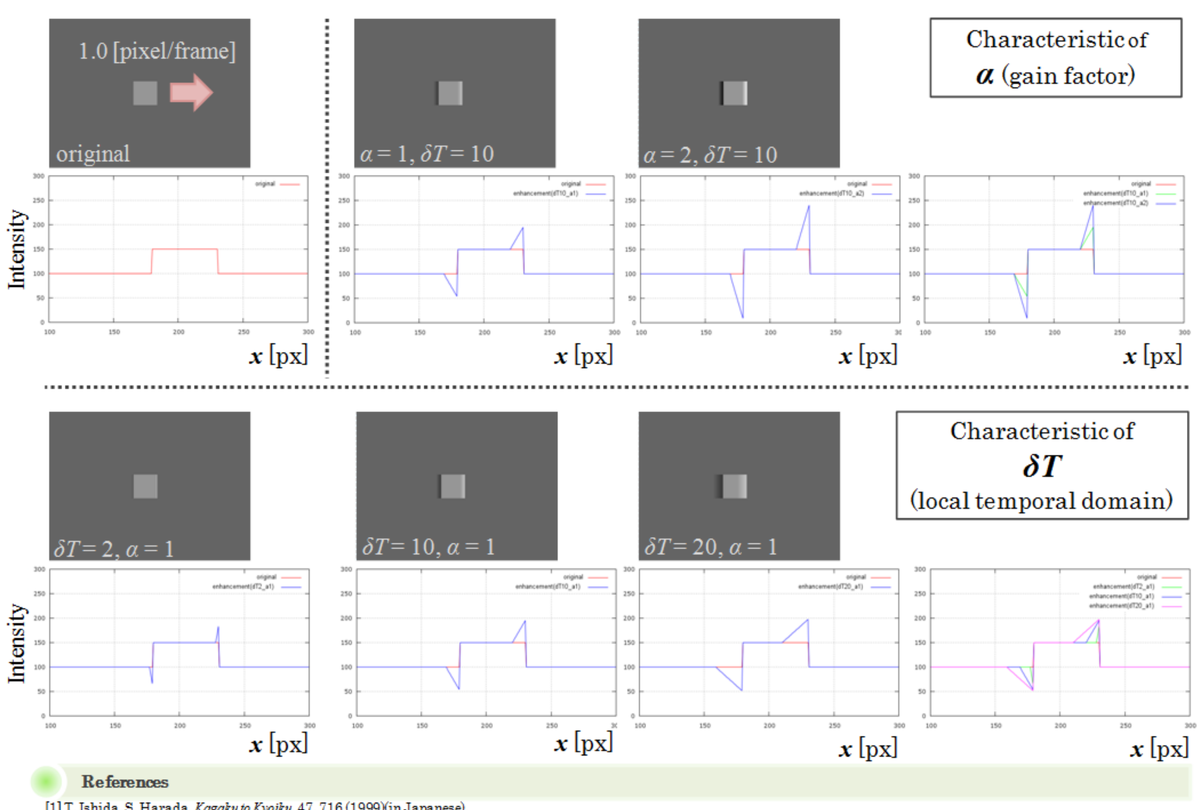
Velocimetry

Original



Enhancement ($\delta T = 2$, $\alpha = 3$)





References

[1] T. Ishida, S. Harada, *Kagaku to Kyoiku*, 47, 716 (1999)(in Japanese).
[2] H. Kitahata, J. Taguchi, M. Nagayama, T. Sakurai, Y. Ikura, A. Osa, Y. Sumino, M. Tanaka, E. Yokoyama, and H. Miike, *Oscillation and Synchronization in the Combustion of Candles*, The Journal of Physical Chemistry, 113, 8164 (2009).
[3] A.K. Pääkkönen, and M.J. Morgan, *Linear mechanisms can produce motion sharpening*, Vision Res., 41, 2771 (2001).
[4] K. Otaka, A. Osa, H. Miike, and K. Okada, *Motion Visualization using an Impulse Response Model in Human Vision*, Spatio-temporal Organization in Non-equilibrium Systems, 23rd February 2013, Fukuoka, Japan.

Conclusions

- Our proposal methods can analyze the convective flow above the candle flame.
- Our motion enhancement method is effective method.
  - Structure of convective flow above the candle flame can be observed more clearly.
  - In velocimetry, accuracy of detection increased.
- In state of oscillation, we observed that some velocity are mixed.