Combined Particle Image Thermography (PIT) and Velocimetry (PIV) in Mixed Convective Air Flows

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Abstract:

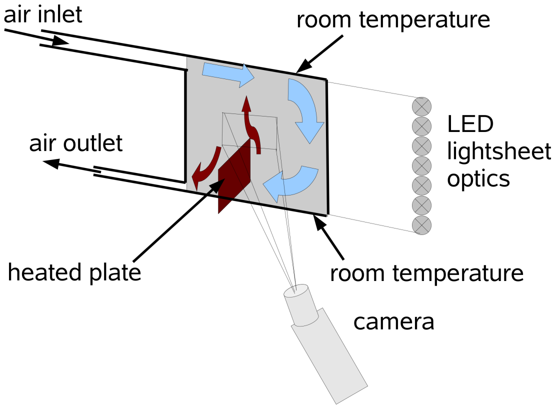
Simultaneous measurements of instantaneous velocity and temperature fields provide a mighty tool to study the dynamics of thermal plumes and their influence on the local and global heat transfer in thermal and mixed convection. An established technique to conduct such measurements in liquids is the combination of Particle Image Thermography (PIT) and Particle Image Velocimetry (PIV) with thermochromic liquid crystals (TLCs) as tracer particles [1]. The intention of our work is to adapt this promising measurement technique to air flows with continuous fluid exchange. Such flows are found not only in many technical applications, like e.g. indoor climatisation, but also in more fundamental thermal convection problems of air with a Prandtl number of $Pr \approx 0.7$. The feasibility of this measurement technique for pure thermal convection has already been demonstrated in a cubical Rayleigh-Bénard cell with air as working fluid [2].

The general requirements which must be fulfilled to apply TLCs as tracer particles in air flows for combined PIT and PIV are the following: First, in order to conduct PIT, they have to provide a temperature depending reflection of different wavelengths with a short temperature response time. Second, for accurate PIV the tracer particles must posses good following behaviour, a high light scattering efficiency is required and a long lifetime. For systems with continuous fluid exchange, the tracer particles need to be continuously produced at a high rate. Further it has to be considered, that the colour play of the TLCs, which is exploited in the PIT measurement technique to locally detect the fluid temperatures, not only depends on the temperature but furthermore on, e.g. the angle between the incident illumination and line of view, the background light as well as the size and the age of the droplets. Consequently, a spatially resolved calibration is needed for high precision measurements, and the used particles have to be generated with a narrow size distribution. While all of the above discussed issues are addressed in our ongoing study, the present paper focuses on recent progress on particle generation, characterisation and illumination as well as image processing.

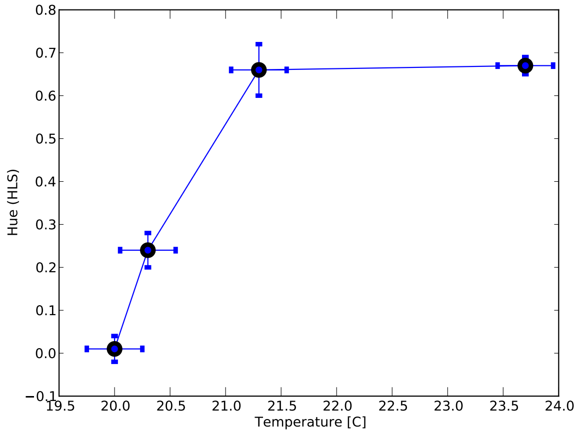
The investigated convection cell has a quadratic cross section of 500 mm × 500 mm and an aspect ratio between length and height of $\Gamma_{xz} = 5$ (see Figure 1a). During feasibility testing the heatable bottom of the cell as well as its ceiling were kept at room temperature and an additional heat source was used for the formation of a spatially fixed area of rising warm air. Furthermore, the particles were sprayed directly into the convection cell with an airbrush system in these first tests. For illumination of the particles a specially developed white light sheet based on LEDs was used. The particle images are recorded with a double shutter colour CCD camera, so that temperatures and velocities could be calculated from the local hue values and the local particle image displacements between subsequent recordings, respectively.

Particle images with different colours were recorded for different mean cell temperatures. Based on these images first points of a hue - temperature calibration curve were determined (see Figure 1b). A feasibility test of combined PIT and PIV was conducted with the additional heat source (see Figure 1a) for the formation of a spatially fixed area of rising warm air. The resulting hue (temperature) and pixel displacement (velocity) fields are shown in Figures 2a and 2b, respectively. Thereby, R20C6W TLCs (©Hallcrest) were used and the presented hue values were obtained using a filter technique based on the saturation value of the HLS colour space. This filtering is necesscary to identify those particles which are neither background nor small particles scattering white light. The local temperatures at the sensor positions are: $T_1 \approx 22.0$°C and $T_2 \approx 20.5$°C. As a result, the areas with warm air (high hue values) are in good correlation with those of upward oriented velocity.

Concluding we can say, that the usage of the tiny TLC particles as tracer particles for PIV as well as their usage as small thermometers in air flows is possible. Additionally we found that the colour active range of the tiny TLC particles (≈ 1.3 K) is way smaller than their nominal range (6 K). An estimation of the limits in the spatial and temporal resolution of this combined measurement technique is an open task. Clarifying measurements with a point wise calibration and investigations of the relaxation time of the crystals will be conducted in the near future.

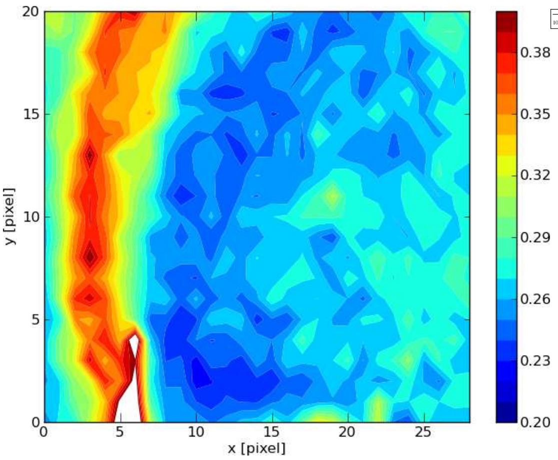


(a)

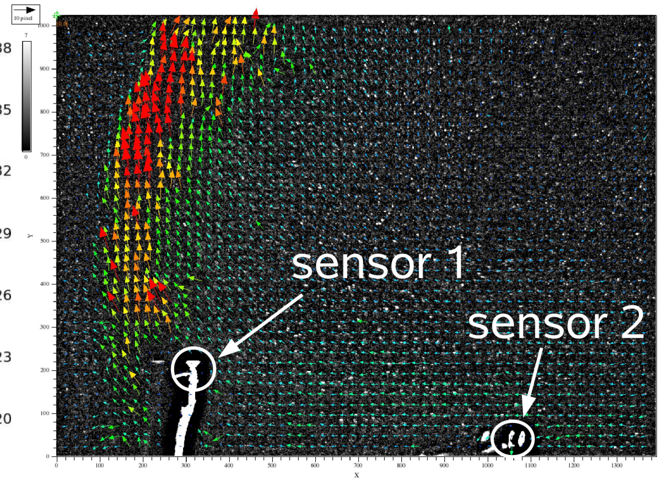


(b)

Figure 1: (a) Sketch of the experimental setup used for first test of combined PIT and PIV, (b) hue - temperature calibration based on four different mean cell temperatures.



(a)



(b)

Figure 2: Instantaneous hue (temperature) and pixel displacement (velocity) fields. (a) Hue values after filtering, (b) to b/w converted image with pixel displacement vectors calculated by means of PIV.

References

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[2] Schmeling D., Czapp M., Bosbach J., Wagner C., (2010): Development of Combined Particle Image Velocimetry and Particle Image Thermography for Air Flows, *International Heat Transfer Conference (IHTC14)*, Washington, DC, USA