The 6th International Symposium on Gas Transfer at Water Surfaces
Kyoto, Japan, May 17-21, 2010
Abstract of poster presented, doi: 10.5281/zenodo.14930

# A new approach for 3C3D measurements of aqueous boundary layer flows relative to the wind-wave undulated interface

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The exchange of scalar tracers such as heat and mass strongly depends on small scale water-sided turbulent structures at the boundary layer. Typical thermographic images of the air-water interface show coherent patterns, probably generated by Langmuir-type turbulences. To accurately describe and parameterize interfacial heat- and gas-transfer, different transport models have been proposed. Yet, concise measurements of the full three-dimensional subsurface turbulence in conjunction with thermographic images are scarce. These measurements are mandatory for validating the models and to gain a better understanding of the underlying processes.
This contribution introduces a novel particle-based technique for measuring three component, three dimensional velocity fields (3C3D) close to the air-water interface.
In contrast to standard PIV or PTV type measurements, depth positions are inherently measured relative to the water surface in a Lagrangian frame of reference. This property of our technique circumvents uncertainties due to locating the position of the water surface. We will present results linking 3D3C turbulence measurements to infrared (IR) thermography.
The measurement principle of the newly proposed technique relies on visualizing the fluid-flow from above the interface with a single camera. Streaks of particles are imaged with a 5 megapixel CCD-camera, enabling a horizontal resolution of 25 $^{\mu m}/_{px}$. The particle-depth relative to the interface is obtained from ratios of the spectral absorbance due to a dye (Tartrazine E 102) added to the water body. Silver-coated hollow ceramic spheres with 100 μm diameter and a density of $\rho \approx 1$ $^{g}/_{cm^2}$ are used for seeding and illuminated by two "ENFIS UNO Tile LED Arrays" with a total radiant flux of 5 W in the wavelength bands $\lambda_1 = 405$ nm and $\lambda_2 = 465$ nm respectively. The measurement principle is sketched in Fig. 1.
The Boundary Tensor [2] is used to obtain a robust feature for the segmentation and the orientation measurement of the recorded structures. This information directly corresponds to the horizontal direction of the particle-movement in the flow-field. The imaged gray-value $g(x)$ along the streak structures of particles depends on the horizontal particle-speed $v_h$, the spectral absorbance of the dye for two wavelengths $z_i$ and the intensity modu-

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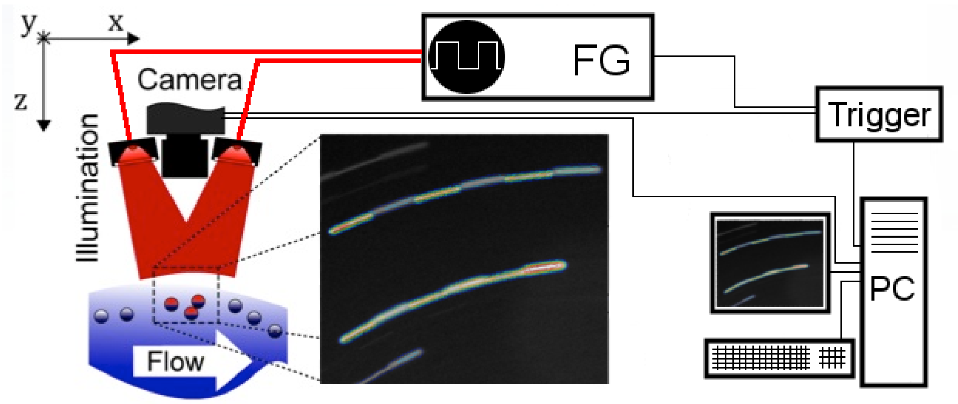


Figure 1: Experimental set-up for the automated measurement of 3D3C flow-fields in the air-water boundary layer. The intensity variation along the streaks enables an extraction of the particle depth.

lation function of both light sources $\Phi_i(t)$. This periodic function defines the intensities of both illumination wavelengths ($\lambda_i$ with $i = 1, 2$) at a given time. This leads to

$$g(x) \propto \frac{1}{v_h} \left( e^{-\frac{z}{z_1}} \Phi_1 \left( \frac{x}{v_h} \right) + e^{-\frac{x}{z_2}} \Phi_2 \left( \frac{x}{v_h} \right) \right) \text{with } v_h = \sqrt{v_x^2 + v_y^2}. \qquad (1)$$

Thus, the only unknowns in this equation are $v_h$ and $z$. We can extract these parameter by an inverse modeling approach. The combination of orientation information and the parameter obtained by inverse modeling results in 3D3C flow information of the flow-field.

The results were validated using spatio-temporal thermographic measurements of the air-water surface. By extracting the flow information of the boundary layer and the net heat flux across the interface using [1], we obtained reliable data for the validation of the proposed method. First combined measurements of thermographic and particle-based techniques led to encouraging results, linking temperature to velocity structures.

Summarizing our contribution, a novel particle based measurement technique for the analysis of momentum and heat transfer at the topmost layer of the air-water boundary was introduced and validated using thermographic measurements. In contrast to the common PIV approaches, this method does not suffer from the correspondence problem and enables measurements directly at the water surface in a a Lagrangian coordinate frame (i.e. relative to the boundary layer). The method extracts 3D3C information of the transport processes at the surface without using a complex multi-camera setup. Image processing routines are used to obtain 3D3C information of the transport processes form the recorded two-dimensional images.

The gained insight in turbulent flow structures and the relation to the temperature field can be compared to numerical simulations [3].

## References

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