

## Measurement of large-scale flow structures in air using a novel 3D particle tracking velocimetry technique

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**Abstract** We report about the development and application of a novel flow measurement technique for convective flows in air. 3D particle tracking velocimetry is used to investigate large-scale flow pattern and particle trajectories. As tracer particles modified helium soap bubbles are applied and the measurement volume with a characteristic length scale of 7 m is been illuminated by halogen bulb and flash lamps.

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### 1. Introduction

Large-scale flow fields occur under a wide variety of circumstances ranging from flows in office rooms, atriums, compartments of vehicles and airplanes to the motion of air in the earth atmosphere. These velocity fields are characterized by a strongly three-dimensional turbulent behavior. Up to now there is no measurement technique to analyze a large-scale three dimensional time dependent flow field in a volume with a characteristic length-scale of 10 m.

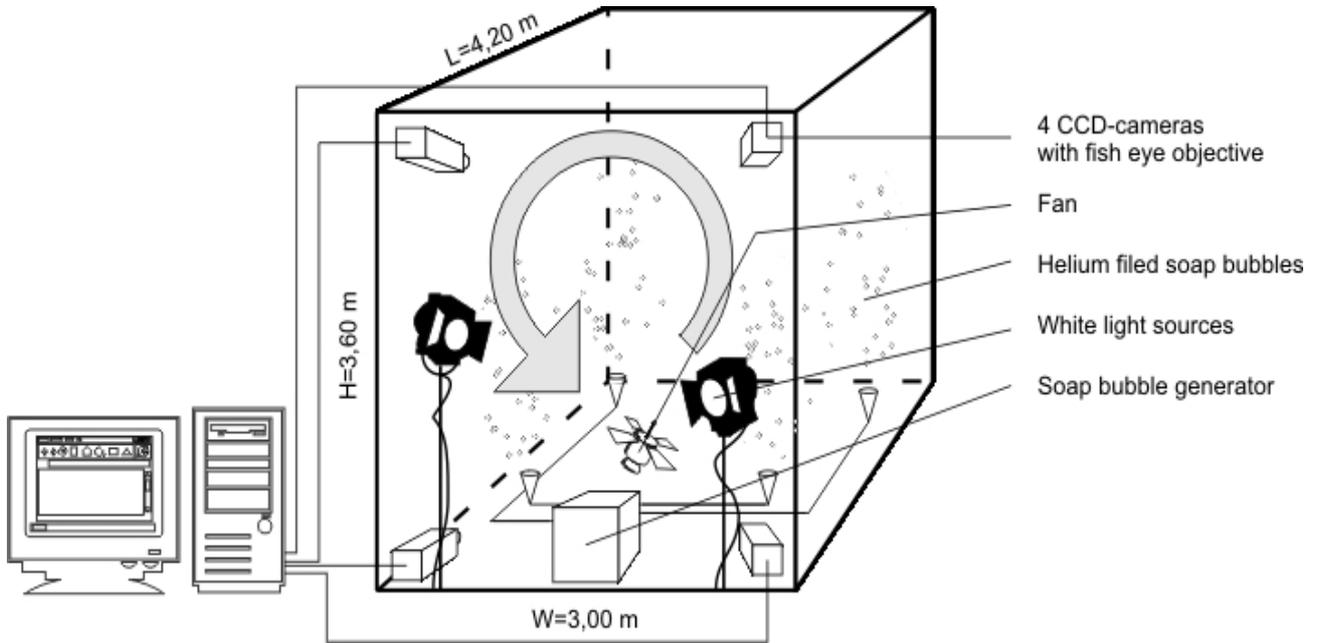
This paper presents first investigations in large-scale convective air flows with a novel three dimensional particle tracking velocimetry (3D PTV). It is based on a digital photogrammetry method using four CCD cameras, recording stereoscopic images of small reflecting, neutrally buoyant tracer particles in a large model cell. The key points of this method are the exact modeling of the geometry of the cell and the recording system, algorithmic aspects of image processing and determination of stereoscopic correspondences - in dense, truly three-dimensional target fields - and finally, the calibration of the recording system (Putze 2005).

### 2. Experimental set-up

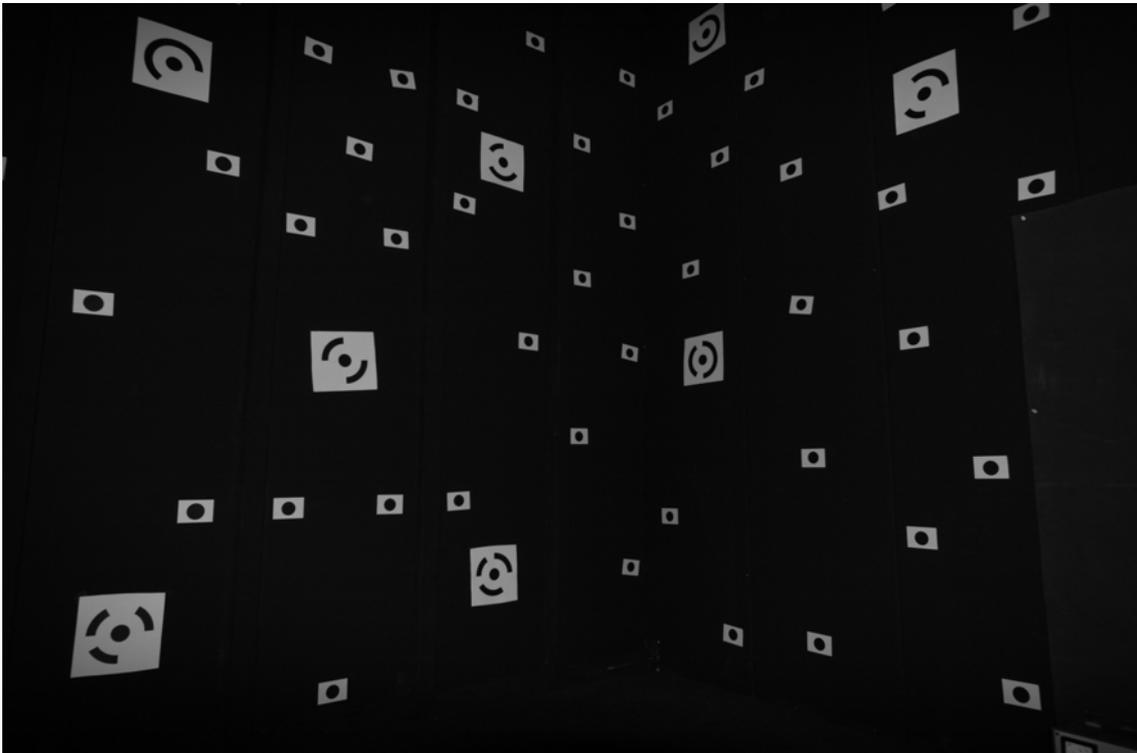
The processing of image sequences with the aim of deriving particle trajectories begins with the determination of particle image coordinates by modified sub-pixel operator. Due to the lack of features allowing a reliable distinction of particles the establishment of stereoscopic correspondences can only be based on geometric criteria of the epipolar line. The large number of particles in image space will often lead to ambiguities during spatial matching, which cannot be solved by a system of two cameras. Therefore, an arrangement containing four cameras and special algorithms using the resulting redundancies are needed.

The first investigations of 3D PTV system were done in a rectangular box with 4.2 m length, 3.0 m width and 3.6 m height, see Fig. 1. A fan generates a forced convection flow in air inside this simple test facility. The four high-resolution synchronised CCD cameras are mounted on one wall. A personal computer is used for the timing of the cameras and the light sources. The soap bubbles are introduced by four nozzles for homogenous seeding inside test facility with 3 mm sized particles. The conventional illumination technique based on a laser light sheet is not applicable due to the strongly three-dimensional flow structure. Instead of the light sheet a diffuse illumination

system for the whole test cell by white light sources or flash lamps enables a three dimensional volume tracking of particles.



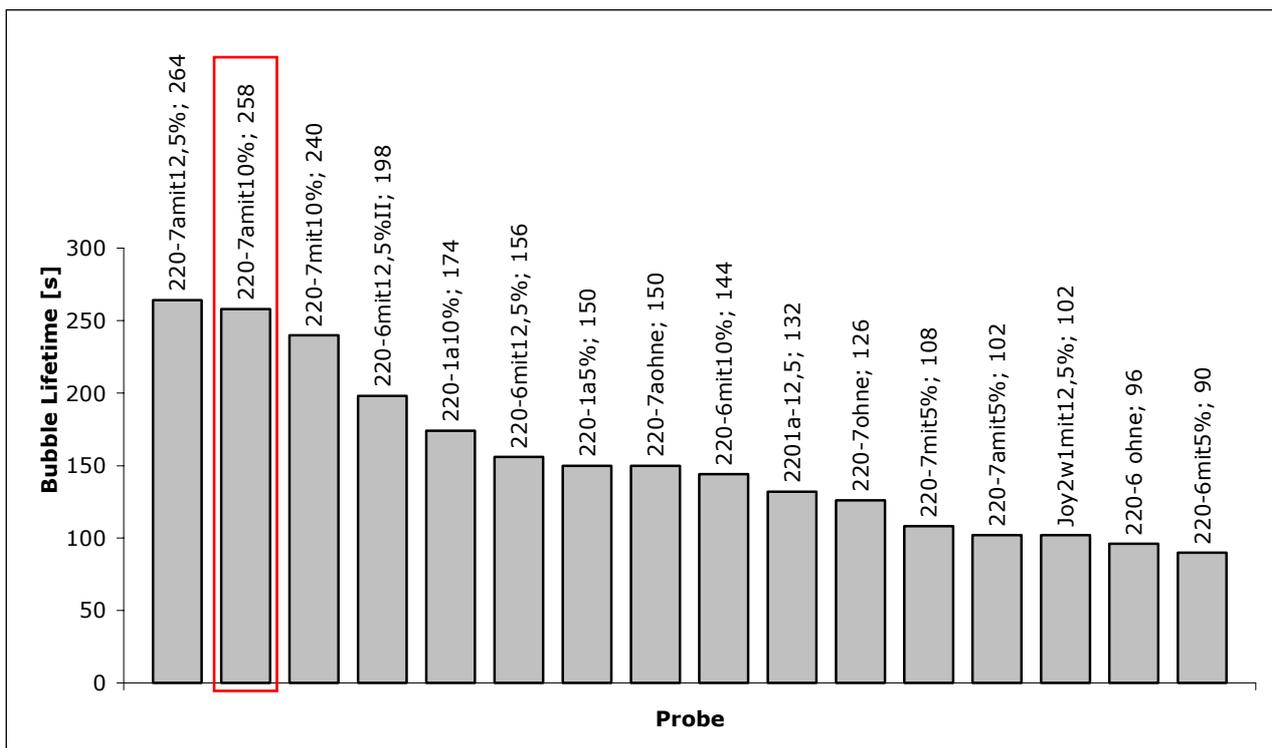
**Fig. 1.** Sketch of the test facility for the investigation of large-scale flow structures using a novel 3D PTV technique.



**Fig. 2.** View inside the test facility with calibration targets on the walls.

First, the four cameras have to be calibrated with the help of a large number of coded targets on the walls of our test facility, see Fig. 2. The resulting calculation of the camera positions allows the estimation of the space coordinates of each detected tracer particle. The particle tracking analysis is done successfully in a simple forced convection flow. The path lines of selected helium filled soap bubbles moving through our test facility were detected by up to 200 contemporaneous images of all four cameras with a rate of 5 frames per seconds.

The helium filled soap bubbles are used as neutrally buoyant tracer particles produced by an in-house bubble generator. In comparison to commercial bubble generators the new system shows a very high bubble generation rate and bubble lifetime as well as stable operation under field conditions, see Fig. 3. To get a higher contrast of the particle images the bubble solution has been mixed with dyes and/or fluorescent substances.

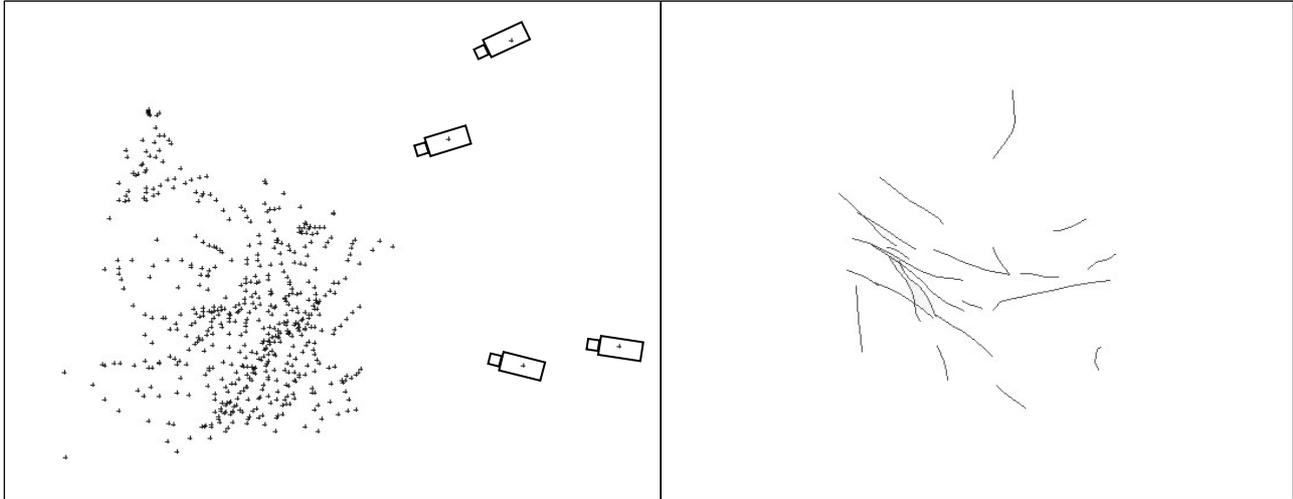


**Fig. 3.** Lifetime measurements of helium filled soap bubbles in a test chamber. The lifetime was determined by counting the absolute number of bubble tracks in a certain time interval by means of CCD-camera images. The red framed probe with a life time of 258 s is used because of it maximum bubble generation rate.

### 3. Results

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**Fig. 4.** Left: Snap-shot of the helium filled soap bubble movement in the test cell, illuminated by halogen bulb lamps. On the right side one can see the positions of the four cameras. Right: Example of the reconstruction of particle tracks inside the test cell in a forced convection flow.

After the testing phase of the 3D PTV, the new measurement method will be applied to investigate the large-scale flow pattern in a Rayleigh-Bénard convection cell called “Barrel of Ilmenau”. This large facility consists of a cylindrical air tank with a variable height up to 6.3 m and a constant diameter of 7 m (du Puits et al. 2006).

## References

- Putze T (2005) Geometric modelling and calibration of a virtual four-headed high speed camera-mirror system for 3-D motion analysis. Grün, A.; Kahmen H. (Eds.): Optical 3-D Measurement Techniques VII. Vol. II, pp. 167-174, Institute of Geodesy and Geophysics, TU Vienna.
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