A Fast Multiple Shutter for Image-Based Metrology

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The success of particle image velocimetry as a well-established standard tool for flow investigations is closely connected to the development of digital cameras. Early applications with photochemical cameras provided high-resolution results, but suffered from ambiguities due to the double-exposure technique and furthermore, the cumbersome and time-consuming wet chemistry inhibited a fast evaluation of velocity vector fields in statistical significant numbers. With the advent of standard video cameras and fast frame grabbers these obstacles vanished (Lecordier et al 1994). Progressive scan cameras finally enabled fast measurements with sub-pixel accuracy free of artifacts caused by the interlace technique (Lai et al 1998).

Current standard PIV cameras contain the so called ‘double shutter’ technique, which captures two frames in fast succession. The exposure time of the first frame is pre-selectable and can be considerably short (lower microsecond range). In contrast, the minimum exposure time of the second frame is limited by the readout time of the sensor (millisecond range). In typical PIV experiments, illumination is provided by pulsed light sources such as lasers. Hence, the long second exposure time is of no concern as long as the background illumination is kept dark enough. However, in some applications the presence of daylight cannot be avoided or the experiment itself involves luminescence such as plasma or combustion measurements. In these cases, the image information of the second frame is superimposed by this background illumination. As a result, the signal-to-noise ratio and finally the evaluation accuracy are reduced. In the extreme case, the image signal saturates, the relevant information is lost and an evaluation is impossible.

Different approaches have been proposed to tackle this problem. External shutters are either to slow (mechanical systems) or affect the image quality (electro-optical systems). Cameras with several image sensors sharing one lens by means of beam splitters can record short exposed frames in fast succession (Raffel et al 1995, Willert et al 1996). Unfortunately, they reduce the light available to the individual image sensors. Moreover, they require an additional effort to calibrate and maintain sub-pixel accurate image matching since de-calibration (vibrations, temperature changes) will directly bias the measurement results.

Similar problems arise in the use of multiple tomographic systems (Lynch & Scarano 2013, Schröder et al 2013).

Using a single image sensor with a modified version of the interlace technique (Parks 2009) is another option. Here, every second image line is left light insensitive and the consecutive frames are recorded with an offset of one line, both of which are not suited for sub-pixel accurate measurements. Finally, special image sensors for high-speed video cameras, fast framing cameras (Etoh & Mutoh 2005) or time-of-flight cameras provide only low resolutions at high frame rates and suffer from high costs.

The new fast shutter mode can be integrated in suited standard PIV cameras without any restrictions to the normal operation. For the first time, two frames with short exposure time can be captured by a high resolution image sensor in fast succession. Both frames use the complete light sensitive area and are completely congruent, i.e. no line displacements or light insensitive lines exist. In double-frame applications, this new mode of operation can outperform even the latest single-chip high-speed image sensors available today. Using the optional third frame enables the implementation of advanced evaluation schemes for PIV (Lynch & Scarano 2013, Schröder et al 2013) and particle tracking.

References