The first “decade” of PIV (1977-1985)
or
From Speckle Photography to Particle Image Velocimetry
or
The prehistory of PIV

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Belgian National Funds for Scientific Research
Von Karman Institute, Brussels, Belgium
AT&T Bell Laboratories, Murray Hill, USA

Now: European Space Agency, Noordwijk, The Netherlands
Optical metrology around 1975: the concept of “speckle”

- Initially devised for measurement of deformations of solids
- Speckle: random intensity pattern due to interference of wavelets scattered by rough surfaces
- Speckle “correlation”:
  - Interferometry (e.g. holographic)
    - Coherent recording, coherent read-out
  - Speckle “photography”:

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coherent or incoherent recording

Coherent correlation
  Laser Speckle Velocimetry
    LSV

Incoherent correlation
  Particle Image velocimetry
    PIV
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Correlation and Fourier Transform
Speckle photography in the 70s (1)

- Detection of double stars by "speckle interferometry" (A. Labeyrie)

FIGURE 5 - A speckle photograph of < UMa (ADS 7158) taken with the 4 meter Mayall telescope on Kitt Peak is shown in (A). The system has a separation of 0.27 arcsecond. The composite spatial frequency power spectrum of 50 such exposures is shown in (B), and the composite autocorrelation is shown in (C). Clearly (B) or (C) lead to more accurate determinations of the system geometry than do direct observations of the speckle pattern as in (A).
Speckle photography in the 70s (2)

- If it works with a solid surface, it should work within a scattering transparent volume

Note the “flat glass” in front of the camera

Fig. 9.5.3 Experimental arrangement for measuring vertical displacement in a plexiglass block.

1977: “annus mirabili”

- If it works within a transparent solid, it should work within a fluid.
And if the fluid moves...

Measuring fluid velocities with speckle patterns

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Received June 1, 1977

A new full-field technique for mapping lines of constant velocity in a fluid flow is demonstrated. The technique utilizes light scattered from scattering sites within a selected plane of interest of the flow field. The laser-speckle...

... that’s a simple way to make quantitative analysis of good old visualization pictures

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PIV 25, 23-24 Sep 09, Göttingen
1977: “the wonder year”(2)

Study of flow pattern in a fluid by scattered laser light

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Sponsored by A. Lehmann, Universität Erlangen-Nürnberg.

The subject of fluid flow measurement by scattering laser light has been keenly pursued over the last decade.1 Light is scattered by micro-sized particles occurring naturally in the fluid or added artificially. Most of these experiments are based on measurement of the Doppler shift suffered by the scattered light and from which the particle velocity and, hence, the fluid velocity can be derived. An important shortcoming of the Doppler method is that it furnishes the instantaneous velocity at a single point in the fluid. To obtain the complete flow pattern, the experiment has to be repeated for different

MEASUREMENT OF FLOW VELOCITY DISTRIBUTION BY MULTIPLE-EXPOSURE SPECKLE PHOTOGRAPHY

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Received 21 February 1978

Measurement of flow velocity distribution in the interior of transparent liquid is made by use of speckle photography. In order to increase effective energy of scattered light, a multiple-exposure method is used. Some of the features of multiple-exposure speckle photography are discussed and an advantage of the speckle technique over the holographic technique is suggested.
First experiments: convection flows

Rayleigh-Bénard convection
Rectangular and cylindrical cells

Note the high-voltage electro-optical shutter

Note the cardboard chopper
First experiments (2)

• Many issues investigated:
  - Recording on B/W film, compromise between sensitivity and resolution (e.g. Kodak Technical Pan, 300 l/mm)
  - B/W film of course, but why?
    • High-end CCDs with 1000x1000 pixels feasible in early 80s,
    • But 24x36 mm photograph with 3 $\mu$m grain provides 8000x12000 “pixels”
• Particle seeding
  - Find the right particle and manage to seed the flow where it should be!
  - Density: to speckle or not to speckle?
• Recording: double or multiple exposures
• Read-out
  - Film processing
  - Local velocity with Young’s fringes
  - Whole-field equal-velocity fringes by Fourier filtering
Local analysis: Young's fringes

Multiple exposure obviously preferred

Which one do you prefer?
Fourier Filtering (1)
Fourier filtering (2)
The development years

• OK, it works. But it is still a laboratory curiosity

• The challenges in 1980:
  - Make fringe exploitation (semi-)automatic
  - Go for higher-speed, unsteady flows
  - Try in gases
  - Demonstrate something in fluid dynamics
Fringe digitization (1)

- Mechanical scanner (scanning mirror + detector on stepper motor)
- Sampling by LDV processor, transfer on PDP 11-34 computer
- Special achievement: cryptographic transfer between PDP-11 and mainframe 😊
- Note: never seriously thought of digitising the flow pictures!
Initial results

Fringe averaging

Again, good inspiration found in speckle photography applied to solid mechanics

Figure 7. Numerical analysis of photodiode output data. (a), $F_1(n)$; (b), $F_2(n)$; (c), $F_1(n) - F_2(n)$; (d), $F_1(n) + F_2(n)$; (e), $|F_1(n) + F_2(n)|^2$. 
Let’s be serious now...

- Fringe digitisation by video camera and frame grabber
- Real-time transfer to PDP11 for “instant” processing
- Slide on motorised translation table
Various processing attempts

Fringe direction determination

Fringe averaging

Fringe autocorrelation
And now the real stuff

- Study of instability of low-\(\text{Re} \approx 2300\) gas jet
- Double-pulse Ruby laser (Joule-class, only 50 mJ/pulse here)
Velocity profile at nozzle

- 3 different pictures
- Note the 1% precision/repeatability
Vortex pairing and transition to turbulence

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Velocity field and vorticity

Note seeding of entrained flow
And another test of precision

- Flow is still axisymmetric at a distance of 2.5 diameters
- Flow is incompressible
- So apparent density change
  \[
  \frac{\Delta \rho}{\rho \Delta t} = - \text{div} \ v = - \left( \frac{\partial v}{\partial y} + \frac{\partial u}{\partial x} + \frac{u}{y} \right)
  \]
  should be zero
- Result:
  \[
  \langle |\frac{\Delta \rho}{\rho}| \rangle = 3.6 \times 10^{-3}
  \]
And, at the end, back to basics

Recording on Polaroid Instangraph 400
Direct positive and no wet processing!
Stamp collection published in JFM (1987)

Figure 8. The velocity-vector field corresponding to figure 7.

Figure 10. For caption see p. 251.
Conclusions

• Computer processing power increased, direct video recording and processing became the mainstream, also solving the limitations with velocity dynamic range

• The battle of the name was lost: LSV was superseded by PIV, better describing the nature of the technique

• … and the author (and his funding authorities) did not anticipate the development of PIV into a “real” standard metrology technique

... but it was a lot of fun