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Editorial

Here, there and everywhere: The art and science of optics at work

Optics, the ancient science of vision and light [1–5] can look forward to a "bright" future [6,7], as its applications are now ubiquitous in fields as diverse as science, engineering, technology, medicine and everyday life. Optical methods play a crucial and often revolutionary role in non-destructive testing, biomedical applications, microscopy, cultural heritage protection, advanced imaging in medicine, development of self-driving cars, astronomy, remote sensing, and manufacturing to cite a few examples.

The aim of this issue is to describe the state of the art of Optical Tools for Metrology, Imaging and Diagnostics, with an emphasis on new technologies, and their wide cross-disciplinary applications.

We have chosen a mixed approach to introduce the readers to this collection of high quality papers. While scanning the images will guide the reader to a short visual journey through optical applications in Metrology, Imaging and Diagnostics, reading the text will provide him/her with a brief introduction to the scientific papers included in this special issue.

This *visual approach*, not exhaustive and largely based on a personal choice, was inspired by several vision-based science books, such as, *Stopping Time-The Photographs of Harold Edgerton* [8] and *Alien Visions* [9], in which optical methods offer a different way of seeing; *Cosmic Imagery – Key Images in the History of Science* [10], which is about the power of pictures in understanding, and *An Album of Fluid Motion* [11] which is about "the treasure of beautiful and revealing photographs" of flow visualization.

1. A visual introduction

Figs. 1–12

2. Optical tools for metrology, imaging and diagnostics

At the core of optics, Optical Metrology, Imaging and Diagnostics are continuing to contribute to shaping advancement in science and technology. Optical techniques are flowering and their role in many diverse fields, from archaeology to medicine, to space science and engineering, can hardly be overstated [27–40]. The extraordinary development of optical methods in the last 50 years has been propelled by two revolutionary changes: (1) the invention of the laser light source in 1960, and (2) the invention of digital recording and the contemporary development of high performance data processing let loose by the advent of the computer era [41,42]. As a matter of fact, current trends in optical techniques imply both revolutionary and evolutionary changes (Figs. 1–12).

The main reasons of success of the optical tools can be summarized in their noncontact approach, flexibility, full-field nature and their easy integration with imaging hardware and image processing [43]. The optical tools treated in this issue are briefly described below.

Schlieren and shadowgraph techniques [18,44] are some of the oldest and widely used techniques for flow visualization [45–47]. Their portability and diffusion can be greatly enhanced by smartphone imaging, as discussed in [48].

Interferometry is probably the optical tool with the highest impact on science and technology [49,50]: from landmark interferometers, such as, Jamin (1856), Rayleigh (1896), and Mach-Zehnder (1891) to holographic interferometry [51,52], digital holography [53,54] and gravitational waves interferometry [55,56].

Optics has continued to play an instrumental role in astronomy since Galileo's time [57] and provides the tools to perform precision metrology. The most accurate measurement technique for precision optical surfaces involves interferometry [58]. A review about emerging technologies in the field is given in [59].

The recent achievements in digital holography are reported in [60]. In [61], an experimental investigation by digital holography of the formation of Hex-PPLN microstructures with double-periodicity in Lithium Niobate crystals using an electrical field poling process is given.

Two-color digital off-axis holography is proposed in [62] for imaging particles and discriminating closely placed ones.

Fringe-reflection deflectometry [63] is a powerful method to measure specular surfaces; an enhancement of this technique is discussed in [64].

The speckle phenomena [65], rediscovered since the advent of the laser in 1960s, gave rise to a large number of optical tools, globally known as speckle metrology [66–68]; its notable techniques include ESPI (Electronic Speckle Pattern Interferometry), also called DSPI (Digital Speckle Pattern Interferometry) [69], Digital Speckle Photography (DSP) [70,71] and digital shearography [72,73]. ESPI can be combined with laser scanning, allowing the characterization of tyres sections', as shown in [74]. If coupled to a laser vibrometer, ESPI can provide quality control of leather in the tanning industry [75]. The joint use of DSP and phase-stepping Fresnel digital holography allows for measuring in-plane and out-of-plane displacements of large objects at long working distances [76].

The most common optical configuration for a shearography system is a modified Michelson interferometer. This device presents some difficulties when working in field. A new compact and robust optical configuration for shearography, based on a Diffractive Optical Element (DOE), is presented in [77]. Shearography can also be adapted to the detection

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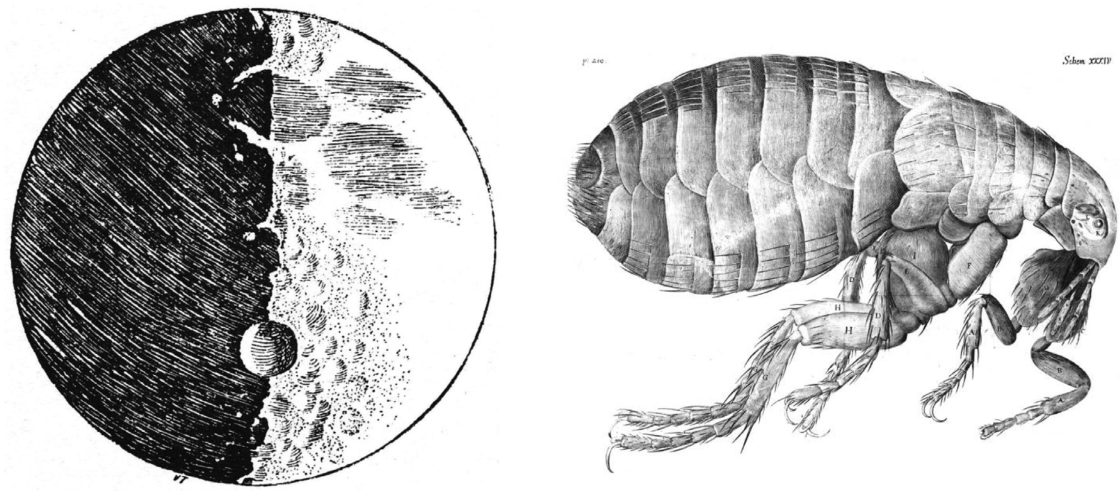

Fig. 1. (Left) One of the famous first published sketches of the moon, as seen through a telescope by Galilei [12]. (Right) The astonishing drawing of a flea from the first illustrated book of microscopic observations by Hooke [13].

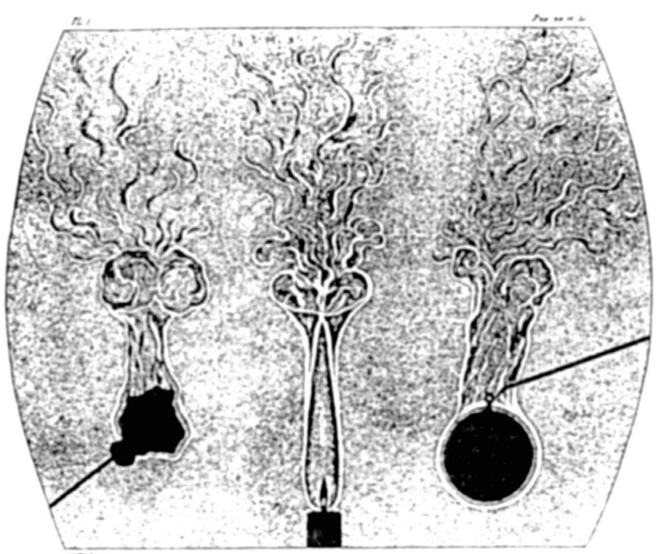

Fig. 2. Jean Paul Marat's drawing of thermal plumes from several objects, including a candle (center), is considered as the first ever published shadowgram [14].

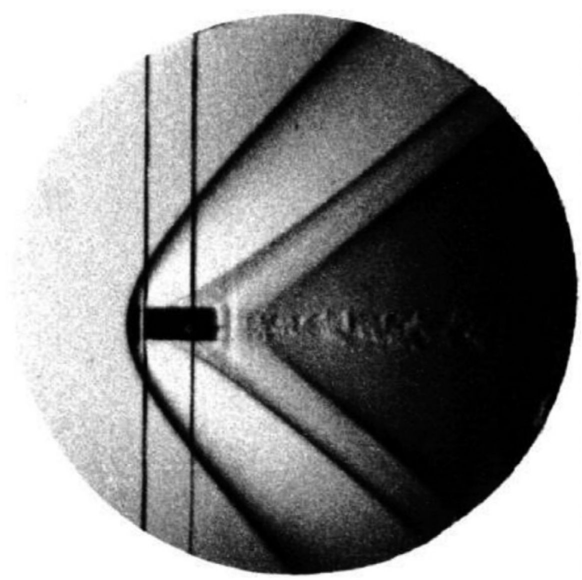

Fig. 3. The original iconic schlieren image of the bow shock wave of a supersonic bullet, published by Mach and Salcher [15]; the bow shock, the tail shock and the bullet turbulent wake are detected.

of adhesion flaws on internal surfaces of flanged joints of composite material pipes [78].

In many optical interferometric techniques, such as holographic interferometry, ESPI, shearography and moiré [42,79], required information is encoded in a phase change; thus the demodulation of a fringe pattern is needed. This explains why fringe analysis has become a crucial tool for a full exploitation of optical methods [80–85]. That how simultaneous estimation of multiple phases from a multicomponent exponential phase (recorded in multi-beam digital holographic interferometry) allows for simultaneous multidimensional measurements from a single recording is shown in [86]. 3D deformations of solid bodies can also be obtained by extending the concept of monogenic function to fringe pattern analysis; this new approach is illustrated by determining the deformation of the heart left ventricle [87].

3D measurements can be enhanced by a novel dual-camera calibration [88] and by calibration of an arbitrarily arranged projection moiré system [89].

Digital image correlation (DIC) [90,91] has had an explosive growth propelled by digital image recording and computer data processing. In DIC, different images of an object are digitally acquired and stored. Then information about the shape, motion or deformation is extracted by image correlation. A low-cost, portable and robust stereo-digital image correlation (stereo-DIC) system for accurate surface three-dimensional (3D) shape and deformation measurements is described in [92]. The system adopts a high-resolution single camera and blue light illumination. The DIC performance depends on the quality of the initial guess of the deformation parameters. An improved feature-based initial guess scheme is presented in [93]. In [94], a morphing-based approach is presented to perform a *one-step* large deformation analysis with DIC. The method has allowed to measure very large deformations ($>150\%$) on an aluminum sample subjected to a pneumatic bulge test. The DIC measurement accuracy can be enhanced by a grey intensity adjustment strategy, as described in [95].

In optical commercial systems, the speed performance is crucial. The features offered by parallel computing were reviewed in 2012 [96]. Current state-of-the-art is discussed in [97], with emphasis on digital image correlation, fringe analysis and tomography.