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OPTICS and LASERS in ENGINEERING

Guest Editorial

Quaternary Optics in Italy, Part I: Historical review; organizational aspects; and contributions in interferometry, holography, speckle techniques and photoelasticity

Lumen propagatur seu diffunditur non solum Directe, Refracte, ac Reflexe sed etiam alio quodam quarto modo, Diffracte (Francesco Maria Grimaldi, "Physicomathesis de lumine, coloribus, et iride" Bologna, 1665).

We believe that a special issue of the journal of Optics and Lasers in Engineering devoted to the optical science and engineering activities in Italy is an excellent opportunity for the Italian optics community to project its strength in this area to the international audience. The aim of the special issue is to describe the state of the art in optical science and engineering in Italy through contributions written by prominent researchers active in the field.

We hope that the special issue will offer a comprehensive overview of the optics related research activities with an emphasis on advances in devices and system applications. The scope of the initiative is to provide an international forum to the principal lines and trends of investigation in optics in Italy. In this context, we invited Italian scientists to write contributions on one of their recent works in optics. The Italian optics community responded with enthusiasm to this project with high quality and original contributions. All the manuscripts have been independently refereed by international reviewers. The special issue contains 46 papers which have been distributed over 4 numbers with each number devoted to specific themes in optics. Overall, about 160 authors from nearly 50 public research institutions, universities and private research centres have contributed to the special issue.

Part I includes 10 papers devoted to interferometry, holography, speckle techniques and photoelasticity. Part II is devoted to spectroscopy and generation of harmonics, and contains 13 papers. Part III includes 11 papers on optical methods and techniques used in testing and characterization of materials. Finally, Part IV includes 12 papers covering different aspects and applications of coherent radiation, optoelectronics, and liquid crystals.

While writing the editorial dedicated to the special issue of Optics in Italy, it would seem in the natural course of things to begin it with a brief although non-exhaustive

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perspective on most important Italian scientists—the forebearers of the country's optics heritage—who have made pioneering contributions to the development of the optical science in Italy. We will present a short chronology of what we believe were the Italian pioneers in Optics, followed by a rapid overview on the way the optics related research activity in Italy is organized. The guest editorial will wind up with short descriptions of optics activities at the research institutions contributing to Part I of the special issue.

1. Italian pioneers in optics: a brief historical overview

"Wherefore I thought it better to write true things that are profitable, than false things that are great. True things be they ever so small, will give occasions to discover greater things through them ...In our method, I shall observe what our ancestors have said; then I shall show by my own experience, whether they be true or false,..." is from Giambattista della Porta's Preface of his famous book *Magiae naturalis* first published in 1558 (Fig. 1) in Naples [1]. Giambattista della Porta (1535–1615) born in Vico Equense, 12 miles south of Naples, can be considered as one of the first pioneers of optics in Italy. His book *Magiae Naturalis* was a best seller of his time and perhaps "the greatest importance of this *Natural Magic* arises from it being the only printed record of an evanescent and little known organization that was among the first scientific society of modern times, progenitor of the Accademia dei Lincei (1600–1630), the Accademia del Cimento (1657–1667), and the Royal Society of London, and indeed all manifold groups into which science is now formally organized" [2]. G. della Porta brought this group of men together, meeting them periodically and performing experiments and investigations at his home in Naples. Imitating the many literary clubs then flourishing in Italy, they called themselves *Otiosi*, meaning men of leisure, and an inalienable condition of membership of the club was that each member must have contributed to a new discovery or to a fact in natural science. In those times when even Galilean scientific methods of investigation were arousing controversy, the use of the word "*Magiae*" in the title of della Porta's book revealed an approach that could at best be termed as pseudoscientific. Interested in different scientific disciplines like optics, mathematics and meteorology, G. della Porta's contribution to optics was mainly related with the discovery of the artificial *camera obscura* to which he added a converging lens. Through the analogy of the *camera obscura* with the eye, he was the first to explain the inversion of the image into the eye, although he continued to believe in the crystalline as the sensing part of the eye. In *De refractione optics*, 1589, he studied refraction and claimed himself as an inventor of the Telescope although it has never been demonstrated that he himself constructed one before Galileo. It should be noted, here, that it was Leonardo da Vinci (1452–1519) born near the village of Vinci who had build the *camera obscura* and made the first analogy with the human eye.

Padre Maurolico da Messina (1494–1575) is known for his works on geometry, theory of numbers, optics, conics and mechanics, and for his books on these topics. Maurolico proposed methods for measuring the Earth in *Cosmographia*, which were


ASPICIT ET INSPICIT

IO. BAPT. PORTAE
NEAPOLITANI
MAGIAE NATVRALIS
LIBRI XX.
Ab ipso authore expurgati, & superaucti, in quibus scientiarum Naturalium diuitiæ, & deliciæ demonstrantur.

I De mirabilium rerum causis.
II De varijs animalibus gignendis.
III De nouis plantis producendis.
IIII De augenda supellectili.
V De metallorum transmutatione
VI De gemmarum adulterijs.
VII De miraculis magnetis.
VIII De portentosis medelis.
IX De mulierum cosmetice.
X De extrahendis rerum essentijs.
XI De myrothecia.
XII De incendiarijs ignibus.
XIII De raris ferri temperaturis.
XIIII De miro conuiuiorum apparatu.
XV De capiendis manu feris.
XVI De inuisibilibus literarum notis.
XVII De catoptricis imaginibus.
XVIII De staticis experimentis.
XIX De pneumaticis.
XX Chaos.

CVM PRIVILEGIO.
NEAPOLI, Apud Horatium Saluianum. D. D. LXXXVIIII.

Fig. 1. Cover of *Magiae Naturalis*, Napoli Ed. Salviani (1589).

later, used by Jean Picard in 1670 for measuring the meridian. He was an astronomer who observed the supernova now known as "Tycho's supernova" which appeared in Cassiopeia in 1572. In 1574, Tycho Brahe published details of his observations. His contributions to optics are mainly reported in "*Photismi de lumine et umbra*", which though completed in manuscript form in 1521 was published for the first time in 1611 in Naples (Fig. 2). In his book, Maurolico described the mechanism of vision and studied the refraction of light through the crystalline.

Galileo Galilei (1564–1642) perfected the telescope into an astronomical instrument, and developed a device for measuring diameters of stars and planets. He also developed a microscope. The revolutianory impact that Galilei had on the scientific world is best summarized by Vasco Ronchi in his book [3] "…*era la volta degli occhialai e di Galileo; che trovavano il cannocchiale e il microscopio e ne traevano scoperte mirabili in cielo e in terra*". Using his telescope, Galileo reported several astronomical discoveries including that of Jupiter having four moons (1610). These were the most powerful instruments of his time and which enabled him to make discoveries that led to the Copernican system.

Geminiano Montanari (1633–1687) developed a reticule for his telescope in order to map the moon. He also worked on a pendulum clock and made lenses, which were

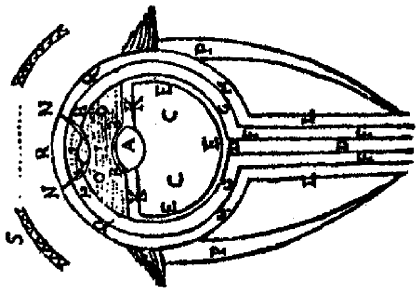

Fig. 2. Section of the eye in "*Photismi de lumine et umbra*" 1611 (Napoli) by Padre Maurolico da Messina.

considered excellent. He later developed a telescope, which he equipped with a reticule for measuring distances with greater accuracy.

Milanese Jesuit Bonaventura Cavalieri (1598–1647) was one of Galileo's friends. He was undoubtedly a mathematician more than an astronomer. His *Geometria indivisibilibus continuorum nova quadam ratione promota* published in 1635 marked a crucial step in the conquest of differential and integral calculus. Bonaventura Cavalieri described for the first time the relationship between the radius of curvature of the surface of a thin lens and its focal length.

One of the most important Italian scientists to contribute to the field of optics is certainly Padre Francesco Maria Grimaldi (1613–1663). He entered the Society of Jesus in 1632 and spent most of his life in studying optical science. Author of the book *Physicomathesis de lumine, coloribus, et iride*, it was published after his death in 1665 (Figs. 3 and 4). He is universally recognized as the discoverer of diffraction of light. Grimaldi described the effect of diffraction when light passed through small apertures, demonstrating that the effect cannot be the consequence of reflection or refraction of light. He can be considered as the predecessor of Newton and Huygens in the formulation of the wave theory approach. He attempted to explain the phenomena of diffraction in assimilating light to be a fluid. The analogy of light propagation with the surface waves produced by a stone falling in the water was expressed by him in the following terms: "*Sicut enim in aqua Circa lapidem tanquam centrum circulariter disponuntur undosi velut aggeres, ita Circa umbram quam proijcit opacum lucido cono immersum, disponuntur lucidae illae series*…"[4]. In his book could perhaps also be seen a preliminary evidence of the observation of the interference effect. Moreover, Grimaldi was also the first to observe the dispersion of the sun's rays in passing through a prism. Padre Grimaldi is also famous for his reflections on the nature of light. He was the first to argue about the evidence of the existence of light: that the light exists outside the eye because we can feel heat in the bodies illuminated by the light.

An engineer from the university of Bologna, Giovanni Battista Amici (1786–1868) constructed microscopes and used them to study biological objects. He reported the development of the catadioptric microscope in 1818.

Educated in physics at Bologna University, Augusto Righi (1850–1920) published more than 200 scientific papers on subjects such as electro-atomic phenomena,

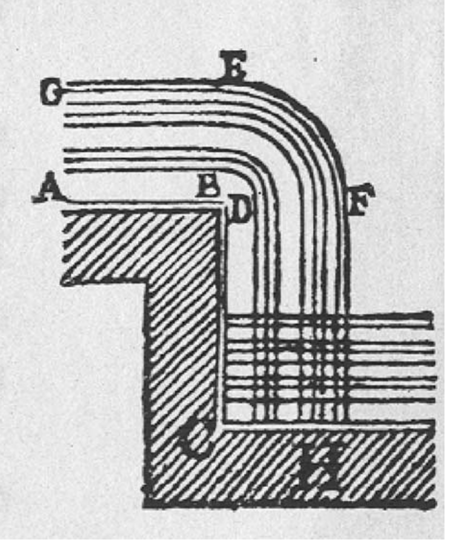

Fig. 3. Diffraction fringe from an edge from "*Physicomathesis de lumine, coloribus, et iride*" Bologna, 1665.

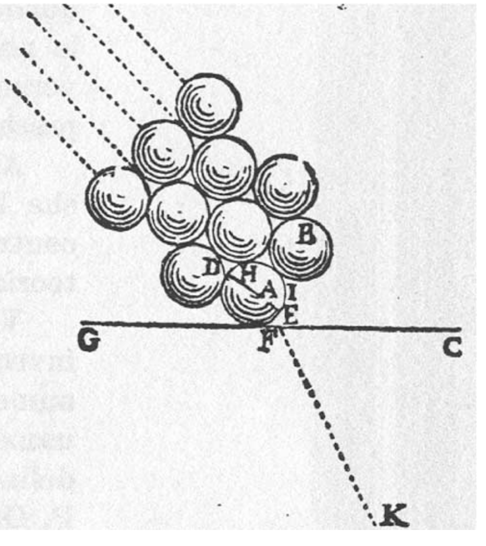

Fig. 4. Theory of refraction from "*Physicomathesis de lumine, coloribus, et iride*" Bologna, 1665.

action of magnetism; electrified particles in gases; electric waves; Hertzian waves; and telegraphy without wires. After Hertz announced his discovery of electromagnetic waves, Righi investigated them, especially their optical properties, and published the results in a treatise, *Optice Elettrica*, in 1897. He noticed that smaller the spheres were on the exciters, the shorter were the waves approaching those of light. Another important contribution due to Righi concerns the moiré effect. Although the moiré phenomenon was first observed by Lord Rayleigh in 1874, Righi was the first to consider the influence of the transmittance of the periodic structures on the moiré fringes in his two papers published in 1887 and 1888 in the *Nuovo Cimento* (Fig. 5). He considered moiré fringes formed by circular and radial gratings and proposed for the first time the use of moiré fringes to measure lateral displacements. The work of Righi is at the basis of all metrological applications of moiré methods in engineering.

Educated in physics at the University of Pisa, Vasco Ronchi (1897–1988) published his famous method for testing large scale optics with simple equipment in 1922. This test became known as the *Ronchi Test*. He was nominated as the Secretary of the Italian Optical Association since its foundation in 1923. In 1925 he became a founding member and the first director of the National Institute of Optics in Florence, a position he occupied until 1975. The research work carried out at this Institute has been published in the journal *Ottica* ever since 1935. The first edition of his book 'History of Light' was published in 1939, followed by the second edition, double the original size, in 1952. Ronchi's research on the history of optics revealed two lost or forgotten pieces: a 10 cm lens dating back to the times of Galileo and a 30 cm metal mirror polished by Amici. Ronchi's hundreds of papers and 30 books were published in Italian as well as in foreign languages. Called to be member of the Optical Society of America in1935, he was later elected "Fellow" and nominated "Emeritus Fellow" of the OSA [5].

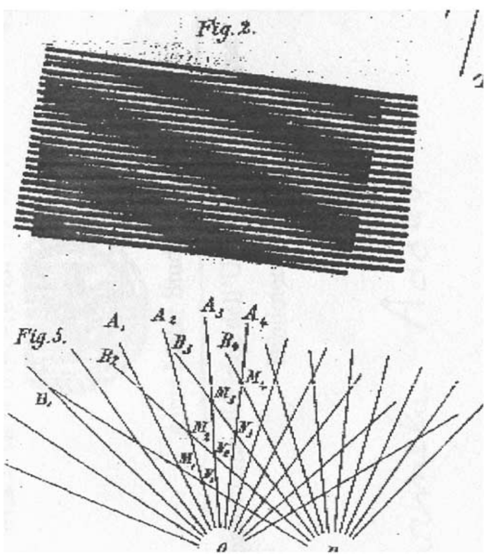

Fig. 5. Moiré fringes from, "Sulle righe che si producno colla sovrapposizione di due reticoli e sopra alcune loro applicazioni", Nuovo Cimento, p. 203–35 (1887).

2. Research institutions operating in Italy in the field of optics

Public institutions perform most of the research activities in Italy; this is especially true in the field of optics. The public research system in Italy depends on the Minister of Education, University and Research (MIUR) and is organized in different kinds of agencies, institutions and universities. Some important institutions operating in the field of optics are given below:

Istituto Nazionale di Ottica Applicata (INOA): is a public research institution, operated by the MIUR, engaged in research and development activities and as well as runs some graduate level programs. The institute is located on the hills of Arcetri in Florence. During the last two decades, INOA has been particularly active in the experimental and theoretical investigations in the areas of Quantum Optics, Optical Metrology and Optoelectronics [6]. Since its foundation, INOA has a strong tradition in the science of vision, exploring the influence of light on the visual system and its environmental role (ergonomy) (Fig. 6). INOA has a strong tradition of collaboration with Industries and public agencies.

In the field of quantum optics, the main emphasis has been on areas such as the dynamics of laser sources; the onset of deterministic chaos, its control and synchronization; pattern formation and recognition in extended optical systems; and non-linear optical effects. In the field of optical metrology, the emphasis has been on the development of novel high-resolution interferometric and holographic devices; non-invasive methods for inspection of paintings and sculptures; and high-resolution microscopy. The research on optoelectronics concerns the realization of inspection systems for quality and process control in industrial and environmental problems. In the framework of European collaboration, optical systems for several applications (solar energy, identification of structural defects, stress measurements, control of mechanical surfaces) have been realized. In the next few years, INOA's activities are planned to be strengthened and its spectrum broadened to include optical investigation of nanostructures in technologies and biomedicine etc.

Since 1980, INOA is responsible for providing post-graduate courses in optics through its "*Scuola di Specializzazione in Ottica*", in collaboration with the University of Florence. As a consequence of various collaborations with other national research institutions, INOA's branches have been established in Napoli, Milano and Lecce, besides those in Florence.

Consiglio Nazionale delle Ricerche (CNR): includes a number of Institutes performing research activities in different branches of optical sciences. The National Research Council is a public organization of great relevance in the field of scientific and technological research. Founded in 1923, its "primary function is to carry on, through its own organs, advanced basic and applied research, both to develop and maintain its own scientific competitiveness, and to be ready to effectively and timely take part in the strategic fields defined by the national planning system" (Italian Law 59/1997). In particular, CNR promotes and carries out research activities, in pursuit of excellence and strategic relevance within the national and international ambit, in the framework of European cooperation and integration; in cooperation with the academic research and with other private and public organizations, ensures the

Fig. 6. Tolomeo or Astronomia by Andrea Pisano; Logo of Istituto Nazionale di Ottica Applicata (INOA).

dissemination of results inside the country. Eight institutes of CNR in different parts of Italy are: *Istituto Isituto di Ricerca sulle Onde Elettromagnetiche*, Firenze; *Istituto di Cibernetica*, Pozzuoli, Napoli; *Istituto di Elettronica Quantistica*, Firenze; *Centro di Elettronica Quantistica e Strumentazione Elettronica*, Milano; *Istituto di Ricerche Elettromagnetismo e Componenti Elettronici*, Napoli; *Istituto di Metodologie Avanzate di Analisi Ambientale*, Tito Scalo, Potenza; *Istituto Motori*, Napoli; *Istituto Materiali Speciali*, Tito Scalo; *Instituto di Biofisica*, Pisa.

National Agency for New Technology, Energy and Environment (ENEA): is the second largest governmental Research Institution of Italy with a staff of 3500 persons. ENEA was originally founded to investigate nuclear energy and to develop nuclear plants. Today, ENEA is covering large sectors of applied research. The Applied Physics Department operating at the ENEA Research Centre of Frascati in Rome, with a staff of more than 50 researchers, is developing laser sources and laser applications. The most characteristic feature of the Division is its rather unique tradition in equipment engineering. Activities carried out in the Laboratories in Portici, Napoli, include optical characterization of solar cells and photovoltaic modules.

Istituto Nazionale per la Fisica della Materia (INFM): The National Institute for the Physics of Matter was established in June 1994 as a national public research institution to perform and co-ordinate research on the physical properties of atomic, molecular and condensed matter systems, to promote the training of scientists and technicians and to contribute to the technological development of the country. The Institute originates from a former Consortium grouping 37 Italian universities and has been since 1960 co-ordinating activities based on joint programs between these universities. INFM is now one of the main five public research institutions in Italy, coordinating the research activities of over 2500 scientists and trainees. As a national research institution, INFM has a fivefold role: to support University research in the fields related to the physics of matter; to promote the participation of the Italian scientific community to international research, with special emphasis on the research carried out at international large scale facilities; to develop in its laboratories advanced research programs complementary to those performed in universities; to support the national research by funding advanced research projects in the field; and, to contribute to the development of the country through the exploitation of scientific results.

The research activities of INFM in the field of Optics are coordinated by the National Section A in close collaboration with other Italian institutions. The activities take place in 21 research units located all over Italy and organised along five thematic lines: Non linear optics and development of innovative sources of coherent light (LONAD); Advanced optical technology (TECHNOPT); Plasma physics and radiation interaction with matter at high amplitudes (PRIMA); Quantum optics and coherent phenomena (QUANTOPT); High resolution spectroscopy and metrology, atomic collisions, molecules and clusters (SPECOLAR).

European Laboratory for Non-linear Spectroscopy (LENS): is the largest interdisciplinary laser laboratory in Italy and is part of a European network of large-scale laser facilities. LENS is associated with the University of Florence, and was established in 1991 as a European scientific research center, to provide advanced laser and spectroscopic facilities for researchers from European countries and to promote and facilitate the exchange of ideas, scientific techniques, and technical skills. Several European universities have participated in the organization of LENS, through agreements with the University of Florence. LENS is directed by an executive council, nominated by the participating European institutions, that elects the director and the associate director. A scientific council, formed by an international panel of experts, assists the executive council in the planning of the scientific program of LENS. LENS has been founded to facilitate scientific collaborations between European researchers in the fields of linear and non-linear laser spectroscopy and laser physics. It provides the most advanced instrumentation and the necessary technical and scientific assistance to the scientists that request access to the LENS facility. LENS is organized to conduct research in atomic and molecular physics, condensed matter under extreme conditions, laser techniques for molecular spectroscopy, optical properties of semiconductor heterostructures, and ultrafast spectroscopy.

Istituto Nazionale di Fisica Nucleare (INFN): The National Institute for Nuclear Physics is involved in a joint project named VIRGO between Italian and French research teams, for the realization of an interferometric gravitational wave detector. The Virgo project consists mainly of a Michelson laser interferometer made of two orthogonal arms each being 3 km long. Multiple reflections between mirrors located at the extremities of each arm extend the effective optical length of each arm up to 120 km. Virgo will be located at Cascina, near Pisa.

Società Italiana di Ottica e Fotonica (SIOF): The Italian Society of Optics and Photonics was established in 1991 with the aim of representing an open forum where all those interested in optics, optoelectronics, electrooptics, photonics, and related areas could freely discuss and exchange information. The motivation to establish a Society for promotion and coordination of cultural and scientific activities in Italy in the field of modern optics had come up from the discussions held during the Fifth National Conference on Quantum Electronics and Plasma Physics, in November 1988, and received full support of the Italian Territorial Committee of the International Commission for Optics. Although most of its first members were from academic and public research institutions, SIOF also succeeded in getting experts from Industry involved with the society's activities, and currently SIOF membership is quite well representative of all the areas in modern optics.

3. Optics activities at institutions contributing to Part I

Department of Mechanical Engineering of the University of Cagliari is involved in the application of optical methods in the field of experimental stress analysis. These activities go back to 1969 with the use of moiré methods in topography. Activities developed over the last 10 years include image processing, fringe pattern analysis using Fourier transform and phase shifting, and applications of holographic interferometry, moiré, and photoeleasticity in stress and strain analysis. Optical tomography and optical methods for measuring roughness, and shape of mechanical components have also been developed.

At the Istituto di Cibernetica del CNR, the optical group has been active since 1970 in applied optics in the field of holographic techniques for optical inspection of materials. Its current activity is basically focused in the development of novel optical measurement techniques with emphasis on the practical application of interferometric and holographic techniques for non-destructive material characterization, wave front analysis and reconstruction methods, optical system design, theoretical and numerical modelling of electromagnetic propagation in scattering media and composite polymeric materials.

Istituto Nazionale di Ottica Applicata, Sezione di Napoli, is involved in different research projects on non-linear optics, laser spectroscopy for gas sensing, development of interferometric methods for characterization of materials and components for opto-electronics and photonics. Optics groups of Istituto di Cibernetica and Istituto Nazionale di Ottica Applicata have been working jointly since 2000 on the above projects. The other joint research projects include the fabrication of new non-linear optical materials for second harmonic generation for high sensitivity spectroscopy and the application of non-invasive optical diagnostic methods for material evaluation by means of interferometric wave front sensing and digital holography.

A joint collaboration between researchers at the Dipartimento di Energetica, Università di L'Aquila, and the Dipartimento di Ingegneria Elettronica, Università degli Studi "Roma Tre", gave rise to a multi-disciplinary group specializing in the application of optical measurement methods in engineering. This research group operating jointly through two distinct laboratories, in L'Aquila and in Rome, covers a wide scientific area, ranging from electronics to applied physics, to heat transfer and applied thermodynamics. Main research interests include optical non-destructive testing of cultural heritage materials, in particular through methods such as holographic interferometry, sandwich holography, ESPI and speckle metrology; development of new optical techniques in industrial metrology, with emphasis on roughness measurement, distance measurement and profilometry; study of heat and mass transfer problems in transparent media; development of new algorithm in digital image processing; research and development of optoelectronic instrumentation and systems to perform measurements in engineering.

The Applied Physics Department operating at the ENEA Research Centre of Frascati in Rome, with a staff of over 50 researchers, is developing laser sources and laser applications. The most characteristic feature of the Division is its rather unique tradition in equipment engineering. Holographic and speckle techniques have been widely applied for structural and modal analysis, non-destructive testing, metrology and for the control of physical parameters during manufacturing. The expertise of the Division in optical interferometric techniques was recently combined with the use of optical fibres for light wave transport, allowing the development of endoscopic speckle interferometers for microscopy applications. The expertise gained in the last few years concerns the development of optical fibre sensor systems for real-time and in situ monitoring of physical parameters.

CESI is a multi-disciplinary applied research center operating in the electricity and energy field. Electro-optics activities have been carried-out at CESI since early 60s and cover a large number of applications. Holography, speckle and shearographic interferometry, moiré and fringe projection techniques have been widely investigated and applied to broad industrial areas. Interferometric fiber optic sensors have been developed for the measurement of strains in civil structures, as dams and bridges, and in industrial plants as offshore rigs. CESI has also designed and built a system for generating and detecting laser induced ultrasounds with the aim of measuring residual stresses in industrial metal components and detecting cracks, delaminations and thickness of coatings in turbine blades.

The research activity of the Dipartimento di Meccanica e Aeronautica of the University of Palermo has in recent years, placed emphasis on the development of automated techniques for the analysis of interference fringe patterns obtained by the use of optical methods in experimental mechanics and in the field of mechanical design. Part of this activity concerns the development of automated methods for the photoelastic analysis in white and monochromatic light. Another field of interest relates to the development of automated techniques for fringe analysis by Fourier transform, which have been applied to holography, shadow moiré and photo-elasticity. Practical applications in the field of machine design such as the experimental determination of the stress intensity factors in components subjected to temperature gradients, the control of the shape of elements obtained by cold stamping, or the analysis of the instability of tubes subjected to inner pressure, have also been implemented.

At the Dipartimento di Meccanica of the Università della Calabria, the main interest resides in the measurement of residual stress and fracture mechanics parameters using holographic interferometry, speckle interferometry and photoelasticity.

The Dipartimento di Ingegneria Industriale of the Università degli Studi di Parma is involved in research activity on moiré interferometry applied to solid mechanics. Their work is based on the precept that the validity of numerically based models of the mechanical behaviour of materials would benefit from experimental information in the form of displacement and strain fields obtained with optical techniques. Moiré interferometry is applied for localized full-field displacement and strain analysis. High-density phase diffraction gratings are typically used to reveal in-plane displacement components with a sensitivity of 0.4 μm/fringe. Applications including the study of composites, metal plasticity, and fracture mechanics behaviour have been implemented.

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Websites of major Research Institutions in Italy:
INOA: www.ino.it
CNR: www.cnr.it
INFM: www.infm.it
LENS: www.lens.unifi.it
INFN: www.infn.it
ENEA: www.enea.it
Minister of Education, University and Research (MIUR): www.miur.it.

Websites of research laboratories contributing in part I:
http://dimeca.unica.it/
http://www.cib.na.cnr.it
http://dau.ing.univaq.it/~laser

http://www. uniroma3.it
http://www.frascati.enea.it
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