NEWSLETTER

COMMISSION INTERNATIONALE D'OPTIQUE ● INTERNATIONAL COMMISSION FOR OPTICS

A stroll through 3D imaging and measurement

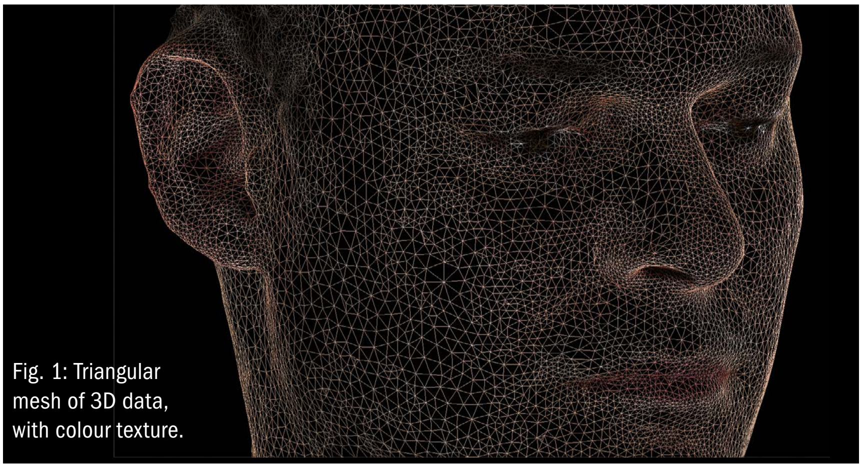
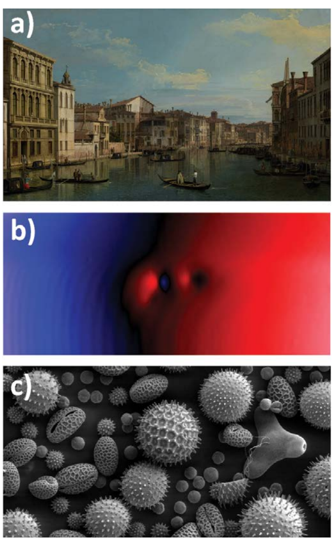


Fig. 1: Triangular mesh of 3D data, with colour texture.

Fig. 2 (below): Perspective (a) and shading (b, c) give pseudo 3D information [1–2].



Light, whether during the International Year of Light or at any other time, is the principal intermediary that links the world we live in with the model of that world we carry in our brains. How that model is produced – how our brains convert the effectively flat two-dimensional images produced by the optics of our eyes into a sophisticated model of the world around us – is one of the wonders of nature and of the evolutionary process. Obviously, stereo vision was sufficient for survival of mankind. But we may ask, is stereo vision already all that we can get? Is there something like a 3D camera? Where are the limits of optical acquisition of 3D data? In this article we attempt briefly to convey an idea of how our eye–brain system works and then consider how specialized 3D optical measuring systems can do a much more thorough and precise job.

We begin by stating a sometimes overlooked fact: the three-dimensional world around us is far from fully accessible with our eyes. Indeed, although the people, cars, ocean shores that we see and photograph are embedded in a 3D space, we see only projections of their textured surfaces onto our retinas. What is actually incident on the retina is a 2D intensity image I(x,y) that is the product of the illumination and the local surface reflectivity. I(x,y) is a 2D data manifold that fails utterly to include any direct information about the local distance z(x,y) for each point (x,y). We see a projection of the world, a projection of three-space onto two-space. Somewhat surprising is the fact that we so readily accept the flat photos, the flat paintings, the flat TV screens as representing "the world" (though as parents we cannot but sometimes help wondering whether, for our children, the flat screens of their smartphones and tablets constitute their actual world). One gets the sense that survival is possible with just 2D vision and 2D displays. Why should this be so?

It is of course not quite true that pure intensity data I(x,y) include no 3D information: we estimate the shape and distance of objects from perspective and from shaded texture, as illustrated in **figure 2**. The texture can be created or enhanced by proper illumination. Scanning electron microscope (SEM) images are intriguing to us because the surface slope is encoded by the secondary electron emission in a way that our brain interprets it as "three dimensional".

Shading by oblique illumination encodes the surface slope extremely efficiently, the tiniest deformations being detectable without the aid of a true 3D sensor. The basic idea is implemented by so-called shape-from-shading or photometric stereo sensor systems for low-accuracy quantitative shape measurement[3].

If 2D images include so much valuable indirect distance information, what, in addition, should a true 3D camera provide and how could we use it? A 3D camera should acquire data about not only the shape of the object, but also its location in space. The shape is commonly encoded as the local distance z(x,y) from the camera reference system to each object position (x,y). Shape data are important in large part because of the following fundamental fact: the shape of an object is invariant against orientation, illumination and texture. The *appearance* of the shape in a 2D image, on the other hand, depends strongly on these parameters. Immediate applications of 3D data are thus to be found in automated inspection, documentation, metrology, and 3D printing; in industry, medicine, cultural heritage; and in other such areas. Instead of the physical generation of objects by 3D printing, 3D virtual reality is useful in entertainment and industrial design. During the last 30 years, optical 3D sensors with high precision have been developed. Whereas common 2D cameras record a dynamic intensity range of about 100:1, the dynamic distance range of 3D sensors may exceed 1000:1 or even

[1] https://upload.wikimedia.org/wikipedia/commons/c/c7/Canaletto_Grand_Canal_from_Palazzo_Flangini_-_JPGM.jpg

[2] https://upload.wikimedia.org/wikipedia/commons/a/a4/Misc_pollen.jpg

[3] R Woodham, "Photometric method for determining surface orientation from multiple images" in Shape from Shading, B Horn and M Brooks, eds. (MIT, Cambridge, Mass., 1989), pp. 513–532.

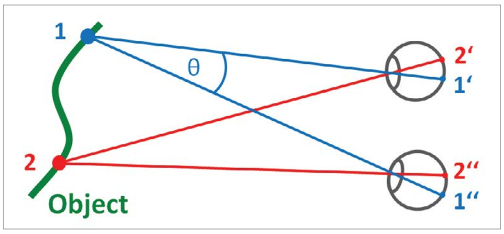
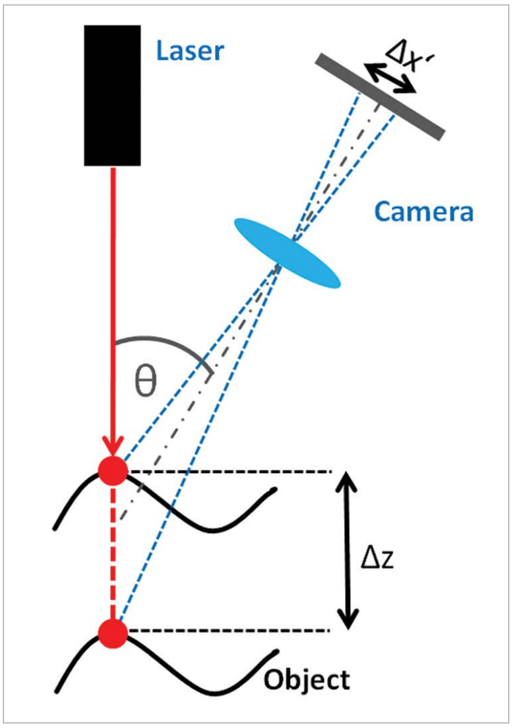


Fig. 3 Stereoscopic vision.

Fig. 4: Stereoscopic entertainment from the mid-19th century to 2015 [4–6].

Fig. 5: The simplest 3D sensor: laser triangulation.



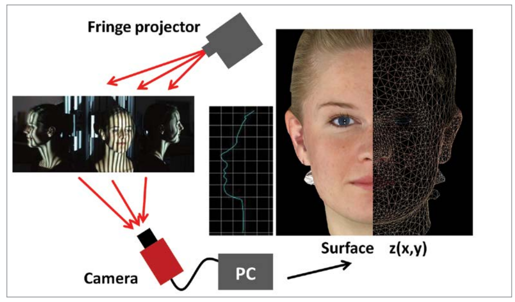


Fig. 6: Phase measuring triangulation: principle and 3D data.

10,000:1. Without a doubt, optical 3D sensors are useful, and indeed there is a billion dollar market for such items.

Consider now stereoscopic vision, which guides us to a major principle of 3D metrology: triangulation. The underlying notion is well known: our eyes see an object from different perspectives. As illustrated in **figure 3**, the two eyes and a given point on the object span a triangle with triangulation angle θ. On the basis of the positions of the images on the two retinas, the brain calculates the local distance of each point and, eventually, the shape of the surface in space. Triangulation has been used in the measurement of distances for thousands of years; the majority of contemporary optical 3D sensors exploit triangulation.

As **figure 4** shows, 3D imaging has a close relationship with 3D display. As early as 1922, 3D motion pictures were produced for showing in movie theaters. Each eye of the viewer sees its own image from a slightly different perspective, separated by colour or polarization encoding. There was no great demand for stereo movies until they were recently reintroduced – with considerably greater quality – by Hollywood and by the computer-gaming industry. Today, a variety of consumer cameras can capture stereo image pairs.

Most of us know that the observation of a stereo image pair allows the viewing of a scene from only a single viewpoint: movement of the head provides no access to different perspectives (although the image pair inherently includes the information to reconstruct different perspectives). Ideally, a 3D display should behave like a "virtual window" such as is provided by a Fresnel hologram: if you move your head from left to right, you should see first the right ear of a person looking at you and then the left ear. The free choice of viewing perspective is clearly a feature that 3D camera data should provide. In the best case, the data should allow access to all possible perspectives. Indeed, sensors and algorithms may provide such data by acquiring many views from different directions and stitching ("registering") the views together. An example is provided in **figure 8**.

A ray optical approach for the acquisition of 3D features is implemented by plenoptic cameras. Plenoptic (or light-field) cameras store the intensity of rays along with their direction. This additional information increases the data-storage requirement enormously, but it enables intriguing a posteriori manipulation of the displayed images, such as choosing different planes of sharp focus or different perspectives. Currently, the pixel count for plenoptic cameras is much smaller than that achieved by conventional cameras.

Triangulation requires the identification of corresponding points as viewed from a distance. An important variant is active triangulation, which allows one to measure the surface of a diffuse but otherwise untextured object (think white walls). In active triangulation, a special pattern is projected onto the object, eliminating the need of an intrinsic surface texture and extensive computation to find corresponding points. The simplest example is laser point triangulation, where the projected pattern is a single laser spot, as shown in **figure 5**. With suitable calibration, the dis-

[4] khnemo.wordpress.com/antique-3-d-cheesecakes-from-swell3d-antique-stereoscopes-from-ortskundeprufung
[5] https://upload.wikimedia.org/wikipedia/commons/b/b0/The_National_Archives_UK_-_WORK_25-208.jpg
[6] blogs-images.forbes.com/insertcoin/files/2014/03/oculus2.jpg

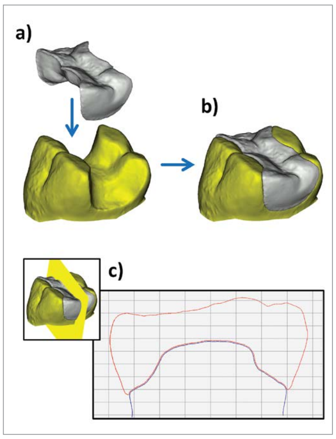


Fig. 7: Tooth with inlay. The inlay was milled according to the measured 3D data of the tooth. High precision is required, since the gap between tooth and inlay has to be smaller than 30 µm to avoid penetration of bacteria.

Fig. 9: Madame Leota, as an example of pseudo 3D-impression [7].

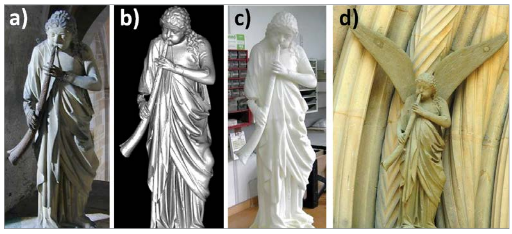


Fig. 8: Copying the "trombone-angel" at the Dome of Bamberg: a) 800-year-old original; b) virtual 3D model stitched from 200 3D measurements; c) casting mould manufactured by 3D printing; d) cast copy, now at the portal of the dome.

tance to the point is easily calculated from the geometry. Laser point triangulation sensors are available for a few dollars. The basic principle can be upgraded by the projection of a line, instead of a point, allowing the measurement of the distance to 1000 or so points with a 1000 × 1000 pixel camera. Projection of many lines allows the acquisition of many thousands of points. This fact leads to the question, where is the limit?

Questions of this kind are of critical importance to 3D measurement, as are questions of accuracy, speed, ease of system setup, and so-forth. It is difficult to acquire "dense" 3D data on the surface of an object, where "dense" means that *each camera pixel* should provide data about the distance to the corresponding object point. Spatial encoding of corresponding points by pattern projection wastes space-bandwidth product: only sparse 3D data can be acquired by pure spatial encoding. Each camera pixel will store information about distance z(x,y), illumination E(x,y), and local reflectivity R(x,y). These *three unknowns* cannot be decoded from *one single* exposure. So we need some additional modality. Commonly, it is time.

The prototypical triangulation sensor, exploiting fringe projection triangulation, uses temporal encoding of each pixel through the projection of a temporal sequence of varying patterns, typically sinusoidal fringes with at least three varying phases (three equations for three unknowns!). The temporal nature of the data-acquisition process implies that neither the object shape nor object position can change during the imaging operation. We cannot acquire suitable 3D data from walking or talking people unless the projector and camera are extremely fast. Nevertheless, fringe projection is the paradigm principle for many macroscopic applications. In **figure 6** we see a face with projected fringes in the centre and two profile image provided by mirrors. The sensor can take data from three directions – from ear to ear – at the same time, with photorealistic quality and dense data. This type of sensor is used, for example, for the planning of cranio-facial surgery.

High-quality data are required as well for the documentation of artwork or to make a 3D copy with a 3D printer, i.e. "3D cloning". **Figure 7** shows a dental inlay that was "printed" (in this case by diamond milling) using data from the measured prepared tooth. In another example of 3D cloning, shown in **figure 8**, a copy was made of the famous "trombone-angel ❶❷❸" at the Bamberg Cathedral in Germany. The 3D numerical model of the 800-year-old statue was stitched together from some 200 3D measurements. The copy now sits at the entrance to the cathedral, allowing the original to be moved inside and protected from the elements.

The 200 measurements had to be made in a stop-and-go process, with subsequent re-orientation of the complicated object. This exhausting procedure can be avoided by "Flying Triangulation ❶❷❸❹❺❻", in which case the sensor can be freely guided around the object. While the subsequent (sparse) 3D data are registered in video real time, dense data are accumulated within a few seconds. The measurement result is immediately displayed, for an interactive guiding of the sensor.

"Flying Triangulation", although single-shot, requires rigid objects for its operation. To acquire the shape of talking or walking persons, we need something like a 3D movie camera, which encodes 3D information temporally resolved in each single frame. Such cameras are available, but as they exploit spatial encoding, there is unavoidable spatial sparseness. The sparseness is commonly concealed to the naïve user by interpolation and display of "smoothed" surfaces with reduced lateral resolution.

Many 3D sensors provide a "perfect" 3D illusion by simply projecting high-resolution 2D texture onto low-quality 3D data. This effect is beautifully exploited in the Haunted Mansion at Disneyland, where a movie of a talking person is projected onto a white painted sphere inside a spherical glass container. A person viewing the projection has the impression of a mysterious woman's head talking within a crystal globe (**figure 9**).

Let us come back to high-quality 3D movies. There is a new approach to the single-shot 3D movie camera ❶❷ that provides improved lateral resolution. Recently, it was shown that with a 1 MP camera, 160,000 true 3D pixels can be acquired. The basic idea is to project 160 narrow lines onto the object, and to view the illuminated object with not one, but two, cameras. The correspondence problem is solved by one of the cameras, which operates with a very small triangulation angle, while the desired precision is achieved by a second camera that operates with a large triangulation angle. Each measured point conveys true, unsmoothed 3D data. Due to its single-shot ability, a sequence of (non-static) 3D models can be acquired. This ability of the camera enables the recording of a "real" 3D movie ❶❷❸❹, since the viewpoint can be freely chosen at any time (unlike as in stereoscopy); see **figure 10**.

Triangulation serves as the basis for 3D measurements on a macroscopic scale, e.g., for people, car bodies, artwork. But optical sensors can just

[7] https://s-media-cache-ak0.pinimg.com/736x/18/9a/f2/189af2eee46fd59969f3e60b29d9cf9f.jpg

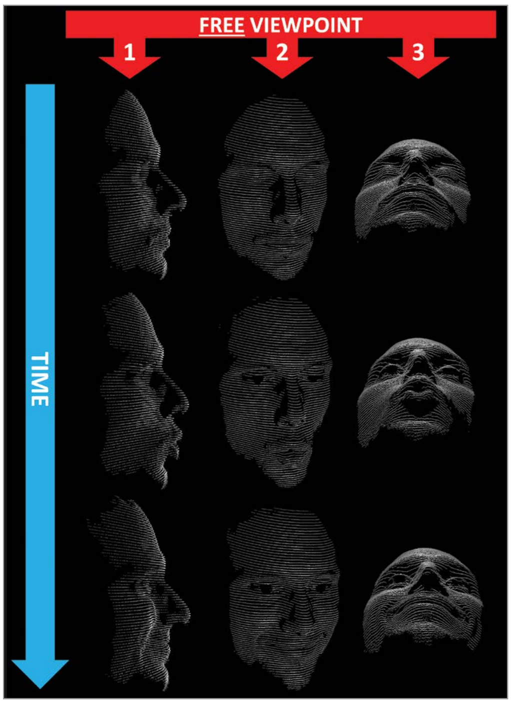


Fig. 10: Three frames of a 3D movie. In each frame, the viewpoint can be freely chosen.

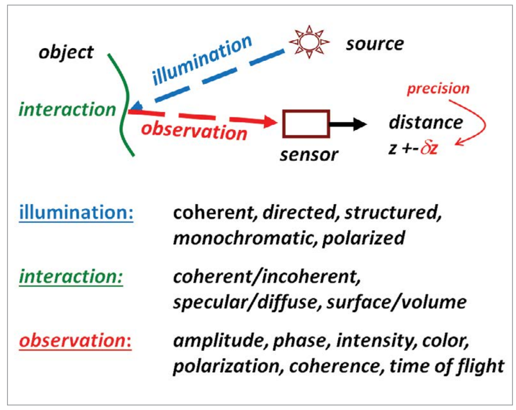


Fig. 11: The canonical optical 3D sensor.

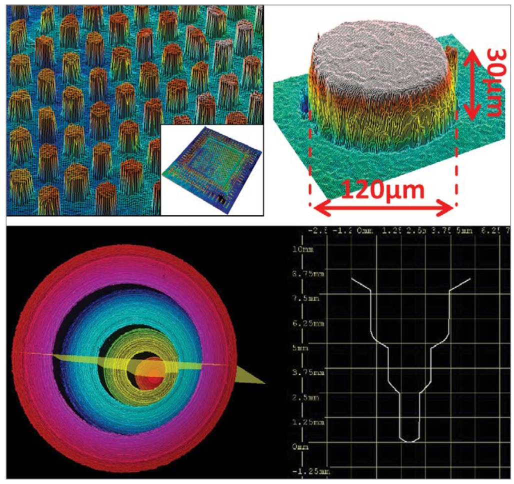


Fig. 12: Rough and smooth objects, measured by scanning white light interferometry.

as well measure the distance to nearby stars or the shape of mirrors with sub-nanometre precision. How do they do this?

Figure 11 displays a canonical sensor model, with all options for illumination, interaction of light with the surface, and the different modalities of information that is conveyed by the object. The combination of options for illumination, interaction, and exploited information enables many different sensors with different limits of physically achievable precision[8], depending on the dominating source of noise. It turns out that there are only a few different sensor principles if we categorize sensors according to the precision limiting source of noise. For example, all triangulation methods are seriously limited by coherent noise (even if they do not use a laser). So we look for other principles.

A straight-forward solution is time-of-flight (TOF) measurement. A laser pulse or temporally modulated laser beam is directed at the object and the time-of-flight of the backscattered signal is measured via fast photodetectors (often by phase correlation). This method was used in the lunar laser ranging project to measure, to within a few centimetres, the distance from the Earth to a reflector array carried to the Moon by the Apollo 11 mission. Today, the shape of large buildings and even of mountains can be measured by terrestrial laser TOF scanning with a precision of a few millimetres. The latest development is the so-called TOF camera with on-chip integration of extremely fast illumination and pixel by pixel detection. Such sensors are already implemented for car-driver assistance.

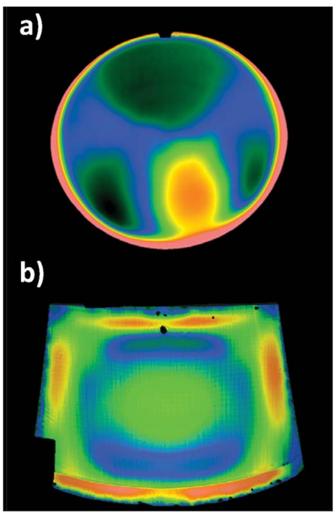
As governed by the speed of light, 1 ns temporal resolution is required for 150 mm depth resolution. Such temporal resolution would seem difficult to achieve, but surprisingly, with a related technique, it is possible to achieve a resolution in time of even attoseconds, yielding a corresponding depth resolution of nanometres. Interferometric methods can be used to measure the difference of the time-of-flight to a certain object point against a reference object. The paradigm example is the use of the Michelson interferometer, ubiquitous in optical workshops, to measure the shape of polished surfaces. In fact, the time-of-flight difference is not measured by a clock, but via the phase difference between the object wave and the reference wave. Because phase differences can be measured with extreme precision, limited only by photon noise, distance variations of atomic dimensions can be detected. Gravitational wave interferometry aims for the detection of distance variations smaller than 10^{-20} m. For very long-distance measurement, it is again interferometry that provides the key. With a stellar interferometer, Michelson and Pease measured the diameter of nearby stars in 1920.

Classical interferometry displays a wide range of applications. However, it is restricted to specularly reflecting objects of regular shape, such as flats or spheres. Scattering ("optically rough") objects display speckles, each speckle characterized by a random phase. Since interferometry operates on the basis of phase measurements, it

[8] G Häusler and S Ettl, "Limitations of optical 3D sensors," in *Optical Measurement of Surface Topography*, R Leach, ed. (Springer, 2011), pp. 23–48.

Fig. 13 (above): Deflectometry – the lens under test reflects the fringe pattern of the background screen. From the deformation of the reflected pattern, the slope of the lens surface can be determined.

Fig. 14 (below): Deflectometry measurement – curvature map of an progressive eye glass (a) and a car windscreen (b).



[9] https://upload.wikimedia.org/wikipedia/commons/2/2d/Retina-OCT800.png

Gerd Häusler is a professor at the Institute of Optics, Information and Photonics, at the University of Erlangen-Nuremberg, Germany. His group's research centers on the physical and information theoretical limits of optical 3D sensors and on practical sensors that work at these limits. Together with former students, he founded 3D-Shape GmbH.

Florian Willomitzer is a PhD student with Häusler's group and working on the real-time 3D movie camera.

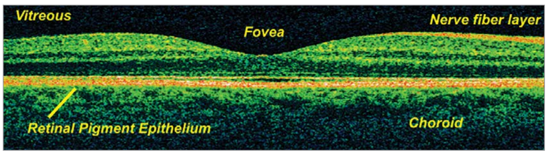


Fig. 15 (left): Optical coherence tomography (OCT) imaging of the retina [9].

Fig. 16 (below): Menu of sensor principles and applications.

Object surface / application	Classical interfer.	WLI	Fringe projection	Laser triangulation	Deflecto-metry
Specular, plane	++	++	--	--	++
Specular free form	-	-	--	--	++
Matt, lambertian	--	++	++	+	--
Machined surface	--	++	+	0	-
Tilted machined surf.	--	+	0	0	0
Deep boreholes	--	+	--	--	--
Volume scatterer	--	0	0	-	--

++ no restrictions   0 suited in some cases   -- impossible

fails to measure rough objects. Some 30 years ago it was discovered that instead of measuring the phase, one can measure the local position of the temporal coherence function ("correlogram"), even in speckles. The method is called white light scanning interferometry or "coherence radar". It displays surprising features. For example, the distance precision is determined only by the surface roughness, neither the stand-off distance nor the aperture limiting the precision. Measurements from great distance and within deep boreholes are possible, as suggested by **figure 12**. Since the phase is of no importance, coherence radar is comparatively insensitive to vibrations, so we can measure human skin *in vivo*. Rough objects can be measured even against a rough reference, enabling the measurement of large objects with large height variation.

We consider now a completely different principle that closes a gap – deflectometry. Specular surfaces are difficult to measure if they are not flat or spherical. If they are clean, we cannot see mirror surfaces, we can only see the mirror image of the illuminating light source. And we see this mirror image only if rays from the light source are reflected into the pupil of the observation system. A further problem is that optical surfaces often require very high precision, for example $\lambda/100 \sim 5\,\text{nm}$. The required depth dynamic range can be up to 1,000,000:1. For simple surfaces, the problem can be fixed by proper reference surfaces. In the absence of a reference surface, a solution can be found that exploits what information theorists call "source encoding" or "redundancy reduction". Deflectometry measures the local slope of the surface, removing from the equation the stand-off distance. The basic idea is sketched in **figure 13**. A large screen containing a sinusoidal intensity pattern illuminates the object under test. A camera sees the object and, simultaneously, an unsharp image of the reflected screen. Note that the fringe pattern is not projected onto the object, but is just seen as the mirror image of the remote screen. The local slope of the object causes a local fringe deformation, as shown in the figure.

With proper calibration of the system – a quite sophisticated procedure – the local gradient of the surface can be inferred from the fringe images. The method is used already for the in-line measurement of progressive eye glasses, of car windscreens, as demonstrated in **figure 14**, and for astronomical mirrors.

Compared to its competitor interferometry, deflectometry displays quite remarkable features. There are no optical elements involved except the sample under test and the camera lens, and the measurement does not depend on any reference or special illumination optics. The object need not be precisely positioned with respect to the sensor. A sensitivity for local depth variations of 1 nm can easily be achieved and even improved by simple means. Deflectometry is scalable for microscopic objects up to large telescope mirrors.

We cannot conclude without mentioning sensors that really acquire 3D data from the bulk of volume-scattering objects, such as skin, the retina, and ceramics. A well-established application is optical coherence tomography, or OCT, of the retina: see **figure 15**. OCT is based on time-of-flight. Signals coming from different depth positions travel different path lengths. These path lengths can be deciphered by white light (coherence scanning) interferometry, as explained above. More efficient is the so-called Fourier Domain OCT, but the basic idea is the same.

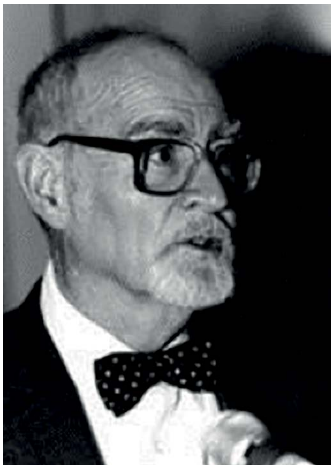
We have completed our walk along the 3D path, often missing many details and having just glimpsed over the fence, but we have learned that there is a wide spectrum of sensors and intriguing applications. Research in this field continues to progress and continues to be fascinating, not least because of new and challenging applications that demand attention.

To bring some order to the reader, we conclude with a guide to the selection of the proper sensor principles for different applications; see **figure 16**.

We gratefully appreciate the valuable and patient help of Prof. W T Rhodes, who not only polished our poor English writing, but contributed with new ideas.

● We invite readers to investigate the many internet links (in blue) that are provided in the article and our homepage www.optik.uni-erlangen.de/osmin.

Remembering John Nelson Howard, 1921–2015



John N Howard, founding editor of *Applied Optics*, former OSA President and ICO Vice-President and Treasurer, Chief Scientist of the US Air Force Cambridge Research Laboratory, spectroscopist, Curator of the Rayleigh Archives, and long-time historian to the optics community, died on 15 April 2015, at the age of 94. Indeed, a man of remarkable character and accomplishments passed away.

I first meet John at the ICO-12 meeting in Graz, Austria, in the fall of 1981. Interestingly, I remember being struck by the resonance in his voice – he sounded more like a radio announcer than a journal editor – and then – I can't recall how we got on this subject – by his consistent readiness to write letters of recommendation for worthy candidates, a truly time-demanding practice. Over the first several days of the conference I heard rumours of John's involvement in the movement to the West of a pair of emigrant scientists from Poland. It was only recently that I learned what actually happened. I write more of that later in these remembrances.

My second meeting with John was six years later, in the summer of 1987, when I was invited by him and his wife Irene to their Victorian home in Newton, Massachusetts, to learn about the *Applied Optics* "editor's office." As I wrote in a recent editorial for *Applied Optics*, this collection of tools, built and used by Dr Howard to administer the Optical Society of America's then 26-year-old journal during his years as founding editor, consisted of a box of 3×5-inch index cards with handwritten names and areas of expertise, accompanied by a small collection of mimeographed form letters. The latter, with notes penned in John's hand, were used to notify authors of the acceptance of their papers, the need for revisions, or an occasional rejection. Of course, there was much more to the editor's office than the 3×5-inch cards and stack of form letters, but most of the remainder resided in John's head, in his extraordinary memory. As John's successor as *Applied Optics* editor, I worked hard to computerize the "editor's office". In truth, however, I have never been convinced that computerization made the office any more efficient.

After reviewing *Applied Optics* editorial procedures, John and his lovely wife introduced me to some of their outside interests and activities. One involved John's role in the preservation of the Henry Jacob Biglow House in Newton, Massachusetts, not far from where John and Irene lived. Built in 1885 and in severe disrepair by the 1970s, the Biglow House was scheduled to be torn down. John organized an effort, the Newton Historic Preservation Association, that resulted in the restoration of the house and its conversion into condominium residences in the

Left: John's wife, Irene. Right: on their wedding day.

1980s, a transformation that was documented and partly funded by the PBS television series *This Old House*. Another memory I have from that visit is of my introduction to John's collection of Gilbert and Sullivan opera libretti. There were 14 libretti extant, he told me, and John had them all. Several years later, when my son Brad was a student at MIT and performed in productions of G&S operettas, John and Irene (shown in the photo at about the time John met her) would be there in the audience.

Later memories of John come from a social visit my wife, ICO Secretary Angela Guzmán, and I paid him and Irene in April 2011. John, who had recently celebrated his 90th birthday, and Irene, who looked as young and fair as she did on my first visit to their home, were as stimulating to talk with as they were in 1987. Subjects of conversation ranged from the history and future of the International Commission for Optics (including his recommendation that the ICO apply for membership as a Scientific Union within ICSU, the International Council for Science) to the various recordings of the Brahms Piano Concerto No. 2, a favorite of both John's and mine. I was pleased to be able to send them a CD recording of the extraordinary Sviatoslav Richter performance of 1960. Subsequently, John wrote me: "I have been busy with my columns for OPN [*Optics and Photonics News*], but last evening I listened to the Richter recording that you sent me. He is certainly a splendid pianist. I have already three or four recordings, but I agree that his playing is about the best I have ever heard!"

John told us of his courtship of Irene. In the late 1940s he was a student at the University of Florida (UF), at a time when UF was a male-only university. "Fortunately," he told Angela and me with a sly smile on his face, "the head of the biology department had a daughter." Irene died in August 2012, leaving John, after 62 years of marriage, with a tremendous hole in his life. I have thought since her death that although John was clearly a star, Irene helped him shine.

For reasons I have never fully understood, John enjoyed statistics. Perhaps for that reason he was always ready to publish his annual *Applied Optics* editorial on that journal's statistics: number of technical articles, book reviews, etc. In any case, I feel an urge to honour his interest in the subject with some statistics relating to his own passing. *Wikipedia* documents deaths of important people, the *Deaths in April* 2015 entries including one on John. Some observations John might have made: of the 526 persons listed, there is only one Howard. There are 11 John's, including two Sir Johns. Ten of the people listed, including our John Howard, died at age 94. Nine were age 100 or older at their deaths. Five, including John, are listed as physicists; John is the only one associated with optics. There were two "notable deaths consequent to the 2015 Nepal earthquake", and two "notable convicted drug traffickers executed by Indonesian firing squad". Well, so much for statistics.

I learned details on John's role in moving Eastern Bloc scientists to the West only recently, from the two scientists themselves. At the time of the ICO meeting in Graz, Poland was in a state of turmoil, for the country had only recently entered the period of its Solidarity Movement. Husband and wife scientists Tomasz and Joanna Jannson managed to travel together to Austria, where they had been invited to present papers at the ICO meeting. They hoped to emigrate to the West, but required help. Conditions in Poland at that time were such that a return home would almost certainly have left them with no opportunity to leave again, perhaps for many years.

Putting themselves at some risk – they could well have been under surveillance – they sought out John, with whom they had had previous journal-related correspondence, and explained their situation to him in hope that he could help. John, through former OSA President Bruce Billings (who had powerful contacts with the US defence and state departments) succeeded in having the Jannsons' names added to the Political Refugee List, referred to at that time as the Reagan List, thereby allowing them to be moved from a refugee camp outside of Vienna, put on a plane, and flown to the US. A scary and exciting time for 38-year-old Tomasz and 29-year-old Joanna. Today, with support over the years from John and other OSA luminaries, Physical Optics Corporation, the company Tomasz and Joanna founded in 1985 employs some 300 people.

Think of that success story as one more example of John Howard's contributions to the optics community throughout his professional lifetime.

William Rhodes is Professor of Computer & Electrical Engineering and Computer Science at Florida Atlantic University and Emeritus Professor (retired) of Georgia Institute of Technology. He served as Editor of *Applied Optics* from 1987 to 1993, following Dr Howard's retirement as founding editor of the journal. Additional remembrances of John Howard by Dr Rhodes are to be published in the July 2015 issue of *Optics and Photonics News* (OPN).

Vadim Parfenov reports on ICO Lecturer Tour in Cuba

Vadim Parfenov attended the Conference on Optics, Photonics and Photosciences (CIOFF 2014), in Havana, Cuba on 13–17 October 2014.

There were approximately 80 attendees, including about 35 students, PhD students and young scientists from Cuba and other Latin-American countries. Within the programme of the conference I gave an invited lecture entitled "Laser Techniques in Artworks Conservation". Among the attendees there was a big group of specialists (about 10) from the Cooperacion Internacional, Officina del Historiador de la cuidade la Habana.

I visited the Institute of Materials Science and Technology (IMRE), which is a branch of the Havana University. At the IMRE, I gave two seminars that overviewed the research activity of the St Petersburg State Electrotechnical University in the field of laser physics and microelectronics. Special consideration was given to the fundamentals of laser techniques intended for the analysis and restoration of artworks. Also, I highlighted some important case studies concerning the use of lasers in cultural heritage preservation in St Petersburg. These seminars were attended by about 15 specialists from the Centro de Aplicaciones Tecnologicas y Dessarrolo Nuclear and from other Cuban R&D institutes.

The impressions that I had during my visit to Cuba were very strong and positive. I was impressed by the high level of research activity and innovative ideas of local specialists. I realised that all the people that I met in Havana are very intelligent, smart and friendly.

I expect that my visit will result in establishing more close collaborative links between the St Petersburg State Electrotechnical University and the scientific community of Cuba. I also hope that my lecturers and seminars were useful and interesting for local specialists and students.

Vadim Parfenov

IOP co-sponsors ICO travelling lecture programme

The Institute of Physics joins the ICO in joint sponsorship.

IOP Institute of Physics

The Institute of Physics (IOP) is joining the International Commission for Optics (ICO) in sponsoring the ICO travelling lecturer programme that enables scientists of international reputation to lecture on modern aspects of optics and photonics.

The programme is particularly aimed at developing countries, but is not restricted to them and it is hoped that the visits will lead to closer collaboration between the visiting lecturers and the host countries.

The ICO has been running the programme since 1988 and this year, for the first time, the IOP is co-sponsoring a lecture series by a UK physicist, Prof. Colin Sheppard. He is a senior scientist at the Italian Institute of Technology, and has been invited to give a series of lectures on 3–7 August at the University of Buenos Aires, Argentina, to mark the International Year of Light.

Prof. Sheppard's research interests include confocal and multiphoton microscopy, phase imaging, image reconstruction, diffraction, scattering, and beam and pulse propagation.

The IOP is matching the $1000 funding provided by the ICO to support the lecture series this year, and will continue doing so when the travelling lecturer award is related to a UK/Irish scientist, a member of the IOP or a country with which the IOP would like to further its relationship.

Contacts

Forthcoming events with ICO participation

Below is a list of 2015/16 events with ICO participation. For further information, visit the new ICO webpage at http://e-ico.org/node/103.

1–4 September 2015
International Conference "Micro- to Nano-Photonics IV – ROMOPTO 2015"
Bucharest, Romania
Contact: Valentin I. Vlad,
tel: +40 21 457 44 67
v_i_vlad@yahoo.com
http://romopto.inflpr.ro

9–11 September 2015
Mexican Optics and Photonics Meeting "MOPM 2015"
Leon, Mexico
Contact: Amalia Martinez-Garcia
tel: +52 (477) 4414200
presidencia@amo-ac.mx
http://congresos.cio.mx/mopm/index.php

11–13 September 2015
OptoAndina 2015
Quito, Ecuador
Contact: Cesar Costa Vera
tel: +59322507144
fax: +59322567848
cesar.costa@epn.edu.ec

14–18 September 2015
Twelfth International Conference on Correlation Optics "Correlation Optics '15"
Chernivtsi, Ukraine
Contact: Oleg V Angelsky
tel: +380372244730; fax: +380372244730
angelsky@itf.cv.ua
www.itf.cv.ua/corropt15/

25–28 October 2015
20th Microoptics Conference (MOC'15)
Fukuoka, Japan
Contact: Ryuichi Katayama
tel: +81-92-606-3135
r-katayama@fit.ac.jp
www.comemoc.com/moc15/

28 February – 2 March 2016
ODF´16
Weingarten, Germany
Contact: Michael Pfeffer
tel: +49 751 501 9834
pfeffer@hs-weingarten.de www.odf16.de/

17–21 May 2016
International Conference on Applied Optics and Photonics 2016
Hanover, Germany
Contact: Eduard Reithmeier
tel: +49 511 762-3334
Eduard.Reithmeier@imr.uni-hannover.de
www.imr.uni-hannover.de/

Responsibility for the correctness of the information on this page rests with ICO, the International Commission for Optics; http://www.e-ico.org/. *President*: Prof. Yasuhiko Arakawa, Director, Collaborative Institute for Nano & Quantum Information Electronics, University of Tokyo, Japan, arakawa@iis.u-tokyo.ac.jp.
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