Questionnaire on activities in radiometry and photometry

Reply from: Instituto de Óptica "Daza de Valdés" (IO-CSIC), D. I. for these quantities in Spain

Delegate: Joaquín Campos Acosta

1. Summarize the progress in your laboratory in realizing top-level standards of:

   (a) *Broad-band radiometric quantities*. No progress in this area during the last two years.

   (b) S*pectral radiometric quantities*:
   - Realization of standards of spectral diffuse reflectance and spectral reflectance factor in the is under consideration once the gonio-spectrophotometer built in the laboratory has been upgraded to measure in this spectral range.
   - A new radiant flux standard in the NIR based on a light trap configuration with InGaAs/InP photodiodes is being radio-metrically characterized.
   - A filter radiometer to measure radiance has een designed and built to measure thermodynamic temperature.

   (c) *Photometric quantities*:
   - Luminous intensity and luminous flux standards have been realized based on high power, white LED emitters.

2. What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?
   - Measurement facility for near field measurement of radiance of SSL sources has been set up by using a CCD camera. Spectral and angular distributions can also be measured.
   - A model to describe the wavefront of white LEDs by using Zernike polynomials has been published.
   - A model alternative to ray tracing to calculate irradiance produced by extended sources at any point is under development.
   - The gonio-spectrophotometer built to study multi-angle reflection properties of materials has been upgraded to extend measurement capability to the near IR and to be able to measure fluorescent samples. Spectral irradiation has been implemented in the system.
   - OLEDs are being studied as candidates for luminance standards.
   - In cooperation with the Spanish Centre for Metrology (CEM) a second filter radiometer for the measurement of black-body radiance has been designed

and built in order to realize the high temperature scale at CEM, according to the future "mise en pratique" for the Kelvin.

- Temperature, pressure and electrical current sensors based on non-linear effects in optical fibre have been applied to new areas of distributed measurement lines in civil engineering. In particular, the ability to measure distributed temperatures over 120 km with errors less than ± 5 ° C and to detect vibrations distributed over lengths of 1.2 km up to frequencies of 40 kHz have been shown.
- Intelligent monitoring system of cut slopes and obstacle detection in railways.
- Metrology for essential climate variables. Sea temperature measurements using arrays of Bragg gratings in optical fibres.
- Filter radiometer to measure thermodynamic temperature based on a PQED radiometer is under test.
- Analytical model for the photocurrent of PQEDs radiometer is under development.
- Spectrophotometric characterization of smart coating mortars based on eco-efficient thermochromics cements.
- Process for the mathematical treatment of BRDF data from calibration sites for remote earth observation satellites, using the method of principal components (PCA) has been developed.

3. What work in PR has been/will be terminated in your laboratory, if any, in the past /future few years? Please provide the name of the institution if it has been/will be substituted by a DI or accredited laboratory.

   Any metrological activity has been terminated in this period.

4. What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

   We have not received any information in this sense.

5. What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?

   I fully support the strategy displayed at the CCPR strategic plan document. Perhaps I would highlight or add:

- Measurement of BRDF of materials and its spatial distribution.
- "Few photon" metrology.
- Optical properties of nano-materials.

- Action spectra of non-visual effects of optical radiation.
- Radiant flux and energy measurements of pulsed sources.

6. Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

- Solid state lighting. Propagation model based on radiant intensity or radiance distributions rather than in ray tracing. It may be very useful for rendering in computer imaging.
- Appearance metrology, particularly on issues attempting to relate the BRDF of gonio-apparent objects with their perceptual properties: colour, translucency, gloss and texture. Issues on modelling sparkle and graininess.
- New fields of optical radiation measurements where IRMDs (imaging radiance meters devices) can play a role on improving existing devices. Examples could be found in meteorological measurements.
- If the CCPR considers the study of nonlinear effects in fibres, including the femtosecond regime, as an interesting research project, the coordination and the collaboration with others NMIs would be necessary.
- The developments of standards for high power pulsed laser in NIR (800 - 2 000 nm), and standards and methods for measuring femtosecond pulses from mode locked optical fibre lasers.
- Nonlinear effects in fibres and crystals and their application in optical radiometry.

7. Have you got any other information to place before the CCPR in advance of its next meeting?

None

8. Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (September 2014)?

✓ A. Ferrero; J. Campos; E. Perales; F. M. Martínez-Verdú; I. van der Lans; E. Kirchner, “Global color estimation of special-effect coatings from measurements by commercially available portable multiangle spectrophotometers". Journal of the Optical Society of America A: Optics and Image Science, and Vision, vol. 32, pp. 1-11
✓ Rosa Weigand; Pablo A. García; Joaquín Campos Acosta; Jacobo Storch de Gracia, “Optical transmission properties of Pentelic and Paros marble”, Applied Optics, vol. 54, pp. B251-B255.
✓ Berta Bernad; Alejandro Ferrero; Alicia Pons; Joaquín Campos; Maria Luisa Hernanz, “Upgrade of goniospectrophtometer GEFE for near-field scattering and fluorescence radiance measurements”, SPIE Proceedings vol. 9398, pp. 3 93980E.
✓ Eric Kirchner; Ivo van der Lans; Esther Perales; Francisco Martínez-Verdú; Joaquín Campos; Alejandro Ferrero, “Visibility of sparkle in metallic paints”, Journal of the Optical Society of America A: Optics and Image Science, and Vision, vol. 32, pp. 921-927.

- ✓ J. L. Velazquez; A. Ferrero; A. Pons; J. Campos; M.L. Hernanz, “Zernike polynomials for photometric characterization of LEDs”. Journal of Optics, vol. 18, pp. 025605.
- ✓ Andreas Höpe; Annette Koo; Francisco M. Verdu; Frédéric B. Leloup; Gaël Obein; Gerd Wübbeler; Joaquín Campos; Paola Iacomussi; Priit Jaanson; Stefan Källberg and Marek Šmíd. Multidimensional reflectometry for industry" (xD-Reflect) an European research project. Proc. SPIE 9018, Measuring, Modeling, and Reproducing Material Appearance, 901804 (February 24, 2014);
- ✓ Alejandro Ferrero; Berta Bernad ; Joaquín Campos ; Francisco M. Martínez-Verdú ; Esther Perales ; Ivo van der Lans and Eric Kirchner. Towards a better understanding of the color shift of effect coatings by densely sampled spectral BRDF measurement. Proc. SPIE 9018, Measuring, Modeling, and Reproducing Material Appearance, 90180K (February 24, 2014);
- ✓ Ferrero, Alejandro; Lopez, Marco; Campos Acosta, Joaquin; Sperling, Armin. Spatial characterization of cameras for low-uncertainty radiometric measurements. Metrologia 51 (2014) 316–325.
- ✓ Kirchner, E.; Van Der Lans, I.; Ferrero, A.; Campos, J.; Martínez-Verdú, F.M.; Perales, E. Fast and accurate 3D rendering of automotive coatings. Final Program and Proceedings - IS and T/SID Color Imaging Conference, 2015, pp. 154-160.
- ✓ Gómez, O.; Perales, E.; Chorro, E.; Viqueira, V.; Martínez-Verdú, F.M.; Ferrero, A.; Campos, J. Influence of the effect pigment size on the sparkle detection distance. Final Program and Proceedings - IS and T/SID Color Imaging Conference, 2015, pp. 175 to 179.
- ✓ E. R. Woolliams1 *, K. Anhalt2, M. Ballico3, P. Bloembergen4,5, F. Bourson6, S. Briaudeau6, J. Campos7, M. G. Cox1, D. del Campo8, W. Dong5, M. R. Dury1, V. Gavrilov9, I. Grigoryeva9, M. L. Hernanz7, F. Jahan3, B. Khlevnoy9, V. Khromchenko10, D. H. Lowe1, X. Lu5, G. Machin1, J. M. Mantilla8, M. J. Martin8, H. C. McEvoy1, B. Rougié6, M. Sadli6, S. G. R. Salim6,11, N. Sasajima4, D. R. Taubert2, A. D. W. Todd12, R. Van den Bossche1,13, E. van der Ham3, T. Wang5, A. Whittam1, B. Wilthan2,†, D. J. Woods12, J. T. Woodward10, Y. Yamada4, Y. Yamaguchi4, H. W. Yoon10 and Z. Yuan. Thermodynamic temperature assignment to the point of inflection of the melting curve of high-temperature fixed points, Phil. Trans. R. Soc. A 2016 374 20150044.
- ✓ A Ferrero1, J Campos1, B Bernad1, A Pons1, M L Hernanz1, F M Martínez-Verdú2 and A Höpe. "Consistency analysis of multidimensional gonio-spectrophotometric measurements in interlaboratory comparisons". Metrologia 53 (2016) 1024–1030.
- ✓ Joanne Zwinkels1, Armin Sperling2, Teresa Goodman3, Joaquin Campos Acosta4, Yoshi Ohno5, Maria Luisa Rastello6, Michael Stock7, Emma Woolliams3. "Mise en pratique for the definition of the candela and associated derived units for photometric and radiometric quantities in the International System of Units (SI)". Metrologia 53 (2016) G1, pp. 1-14.
- ✓ Martins, H.F.; Martin-Lopez, S.; Corredera, P.; Ania-Castanon, J.D.; Frazao, O.; Gonzalez-Herraez, M., “Distributed vibration sensing over 125 km with enhanced SNR using Phi-OTDR over a URFL cavity”, Journal of Lightwave Technology, vol. 33, pp. 2628- 2632.
- ✓ Galindo-Santos, J.; Velasco, A. V.; Corredera, P., “Fibre optics wavemeters calibration using a self-referenced optical frequency comb”, Review of Scientific Instruments. Vol. 86.

- ✓ Poudereux, D.; Quintana, X.; Corredera, P.; Geday, M.A.; Otõn, J.M., “Hybrid liquid crystal-photonic crystal fiber tunable interferometer”, John Wiley & Sons Inc., vol. 57, pp. 2075-2079.
- ✓ Monteagudo-Lerma, L.; Naranjo, F. B.; Jiménez-Rodríguez, M.; Postigo, P. A.; Barrios, E.; Corredera, P.; González-Herraéz, M., "InN-based optical waveguides developed by RF sputtering for all-optical applications at 1.55 μm", Photonics Technology Letters, Vol. 27, pp. 1857-1860.