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Analog-digital photonics 3D irradiance mapping

Nabeel Riza

A hybrid device measures light power in 3D without the disadvantages of mechanical micro-optical components such as lenses or easily saturating imaging devices.

Knowing the power distribution in a light beam is critical to proper design of optical systems. Accordingly, the optical sources and lasers community is constantly challenged to provide robust imaging solutions for a variety of optical sources and the irradiance (or optical-power) distributions of their system interconnects. CCD cameras are typically used to capture 2D optical-irradiance maps. But when irradiance levels are high, CCDs saturate. Consequently, mechanical solutions such as slit, knife-edge, and pinhole image mappers are typically used to measure light power in 2D space. Determining the 3D map of the irradiance distribution of light involves moving a 2D mapping device along the propagation direction of the optical beam. But the mechanical motion of components such as lenses or imaging devices reduces the robustness and reliability of the characterization. Finding an alternative to these micro-optical components would improve light-measurement technology considerably.

We previously proposed and demonstrated the power of combined hybrid digital-analog photonics for signal-processing applications.[1,2] Within the same hybrid theme, we recently devised a motion-free, analog-digital photonics solution for measuring 3D light irradiance.[3–5] Figure 1 shows the basic system, which uses a digital-micromirror device (DMD) and, as the analog element, an electronically controlled variable-focal-length lens (ECVFL). Essentially, this system constitutes a 3D imaging sensor for capturing remote-scene object shape and irradiance in both ambient-light (passive) mode and active laser-based operations.

Traditionally, a 2D irradiance-capture device (e.g., CCD or 2D mechanical profiler) is moved along the optical propagation axis to sample multiple 2D planes of the 3D irradiance pattern. In the system shown in Figure 1, the motion of the 2D irradiance planes is produced by changing the voltage-controlled focal length of the ECVFL. Whether or not to use spherical lenses S1, S2, and S3 depends on the light source and the properties of the optical system. The functional core of our system is a DMD-based, within-chip, software-programmed 2D spatial sampler (e.g., knife-edge, slit, or pinhole shape) on the 2D incident-irradiance plane on the DMD. We previously demonstrated this mapper for a number of light sources.[6–10] For example, Figure 2 shows the mapping experiment for a short-wave (e.g., 1550nm) IR heart-shaped source—see Figure 2(a)—that was first imaged with a CCD using an optical attenuator and then with the DMD-based mapper operating in pinhole mode: see Figure 2(b). The figure shows the correct capture of the heart-shaped light source.

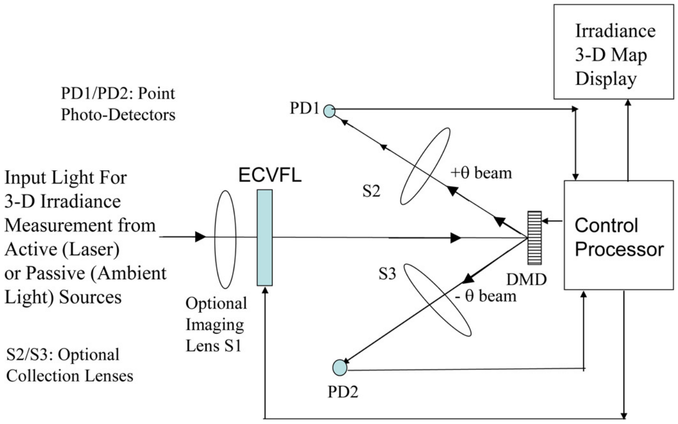

Figure 1. *Proposed optical source 3D (x, y, z) irradiance-mapping instrument using a digital-mode digital-micromirror device (DMD) spatial sampler with an analog-mode electronically controlled variable-focal-length lens (ECVFL) with focus control.* $\pm\theta$*: Tilt angle.*

As a first step toward 3D irradiance mapping, we used our system to measure the 3D divergence properties of a known Gaussian (i.e., focused) laser beam. Figure 3 shows the horizontal or x-direction results of measuring the single-mode Gaussian beam's minimum waist, w_{0H}, and its location, d_{1H}, along the optical axis of a 633nm helium-neon laser beam (vertical or y-direction measurements not shown). According to the

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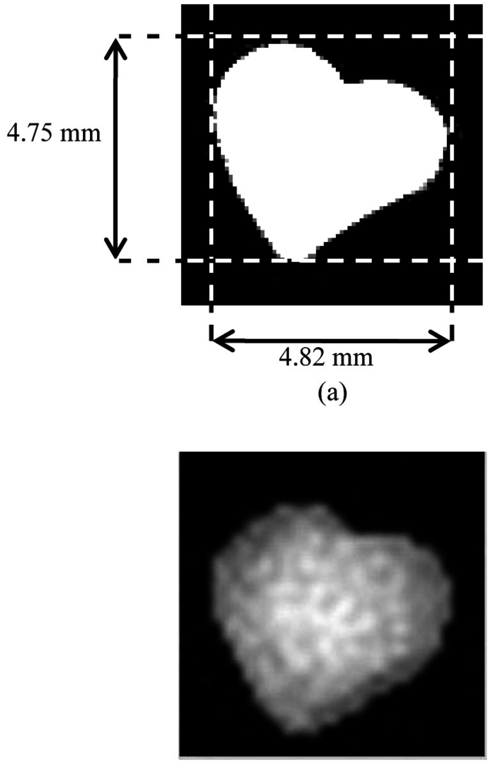

(b)

Figure 2. *Optical-irradiance 2D mapping of an incoherent light source (an IR heart-shaped target) using the instrument shown in Figure 1. (a) IR heart-shaped object image captured by an IR CCD. (b) Heart-shaped image formed using the analog-digital hybrid instrument.*

experimental curve fit, the values of the unknown beam parameters are $w_{0\mathrm{H}}$ and $w_{0\mathrm{V}}$ = 324.27 and 324.71μm, respectively, and $d_{1\mathrm{H}}$ and $d_{1\mathrm{V}}$ = 25.8 and 25.1cm. Based on these experimental values, we found a beam-divergence half-apex angle for the 633nm laser tested of 0.62mrad in both directions. These results are in excellent agreement with the laser manufacturer's datasheet values of minimum beam radius $w_0 = 325\mu$m and beam divergence half-apex angle $\theta = 0.62$mrad.

In summary, the combined power of an analog-controlled ECVFL and a digitally controlled DMD delivers a novel 3D irradiance-mapping instrument that eliminates the need for lens-optic motion, resulting in inherently robust and repeatable 3D irradiance measurements. The proposed instrument has potential application in a wide range of optical sources, including characterization of lasers and passive-light-based 3D objects. As a next step, we intend to fully develop the instrument for use in science and engineering.

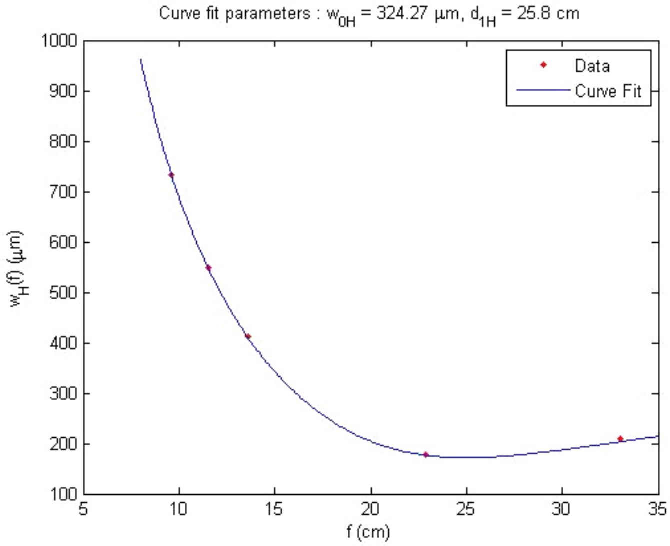

Figure 3. *Experimental least-squares curve fit for the single-mode Gaussian laser based on the beam-waist parameters measured by the 3D irradiance system.* $w_H(f)$*: Minimum-beam waist in the horizontal direction (x–y plane).* d_{1H}*: Relative location of the beam waist.*

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