High resolution optical characterization of NIR light sources for 3D imaging

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Abstract

The great development of low cost and compact 3D imaging for various applications like face-recognition, machine vision or LIDAR for automotive has introduced new requirements in terms of NIR light source characterization. In all the cases, precise characterization of the light source emission properties in all its angular aperture is mandatory to get accurate 3D images. In addition, all these sources must comply safety regulations and must be verified during the fabrication process. The paper introduces a new Fourier optics system dedicated to this task.

Near Infrared, VCSEL, 3D imaging, Fourier optics

1. Introduction

A long time restricted to confidential or professional applications, the field of 3D imaging has seen recently the appearance of many low-cost sensors for different consumer applications. One of the most iconic application is the launch of the Apple IPhoneX with face recognition capacity in 2017 [1]. The Face ID sensor consists of two parts: a "Romeo" module that projects more than 30,000 near infrared (NIR) dots onto the user's face, and a "Juliet" module that reads the pattern. The reliability of the technique is strongly dependent on the NIR light source that must be characterize precisely for all the phones on the production lines. Another booming application is the light detection and ranging (LIDAR) sensors for autonomous driving cars that must provide a real time picture of the 3D environment of the vehicle. Most of the solutions currently investigated uses high power NIR laser sources to make measurements up to 300 meters of the vehicle [2]. The accuracy depends on the laser pulse width and the range of detection of its power and its emissive cone. Large power of several tens of watts are necessary to reach 200-300 meters range

Like for other laser sources, the flux emitted by NIR laser diodes needs to comply safety regulations [3]. The safety standard IEC60825-1 specifies a maximum permissible exposure limit to ensure eye and skin safety. This limit applies to an aperture of 7mm corresponding to the human eye aperture at 10cm. Consequently, the angular emission of each source must be measured for all its aperture without losing any light ray and a 4° integration must be applied to check the safety criterium.

Different techniques have been developed to measure the angular emissive properties of NIR laser diodes. Beam quality of high-power vertical cavity surface emitting laser diodes (VCSELs) can be evaluated using ISO 22146 procedure [4]. The laser beam is transformed through a lens such as to form a beam waist along the propagation axis and different images of the beam at different distances are performed with a CCD camera. A fit is then applied to determine the M^2 factor, the laser waist and the divergence angle. This method is limited to low angle emissive cones and does not provide any detail on the emissive cone of the source [5]. To obtain a far field emissive pattern, standard goniometric methods can be applied but high angular resolution require several hours of measurements [6].

In the following we present a new system dedicated to the characterization of NIR sources that measure the angular emission of a source with a high resolution and its power with great accuracy. This system is based on Fourier optics principle that is used to measure viewing angle properties of displays for more than 25 years. ELDIM has proposed the first commercial equipment based on this technique in 1993 [7]. Since then, these systems have been improved throughout years to reach extremely high performances at every level [8] and new capacities such as multispectral measurements [9] or polarization analysis [10]. The needs for measuring NIR light sources are quite different than for display viewing angles. In the following we explain these new constraints and the performances of the new system. Different examples of measurements are also reported.

2. Experimental details

NIR Laser Sources & Safety Regulations: the emitted radiant flux needs to be limited to comply with safety regulations [3]. The safety standard IEC60825-1 specifies maximum permissible exposure (MPE) limits that ensure safety which must be verified by measurement in specific geometric conditions that simulate human eye vision (cf. figure 1.a). In the wavelength range 400-1100nm, the advised observation distance is 10cm and the aperture is fixed to the maximum human eye pupil diameter (7mm). The maximum permissible irradiation falling on the aperture is dependent on wavelength, total exposure time, timing of the active light source and the light source geometry. If the source is elongated the perceived radiation is spread over a larger aperture (38.5° for human eye) and the permissible irradiance that extend over the retina, is larger (cf. figure 1.b).

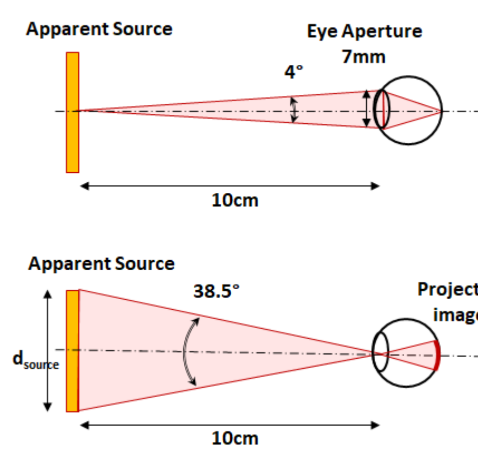

Figure 1. Geometric considerations for safety regulations

Standard Fourier optics: Fourier optics are classically a combination of lenses that collect all light rays emitted by one spot and refocus them on a Fourier plane. Each point on this plan correspond to one light ray direction. In ELDIM patented Fourier optics configuration this plane is refocused on an imaging sensor with a diaphragm in between the two planes that is in direct view of the emissive surface (cf. figure 2.a) [11]. The light source is seen at infinity and the system is focused on the source in the inverse space. The diaphragm defines the spot size independently of the angular aperture of the system and the spot size increases with the incidence angle like a spectrometer on a goniometer. This cosine compensation increases the light collection within larger spot size at high angles. Consequently, the viewing angle of displays can be measured correctly up to very grazing incidence (±88° maximum angular aperture for the ELDIM systems).

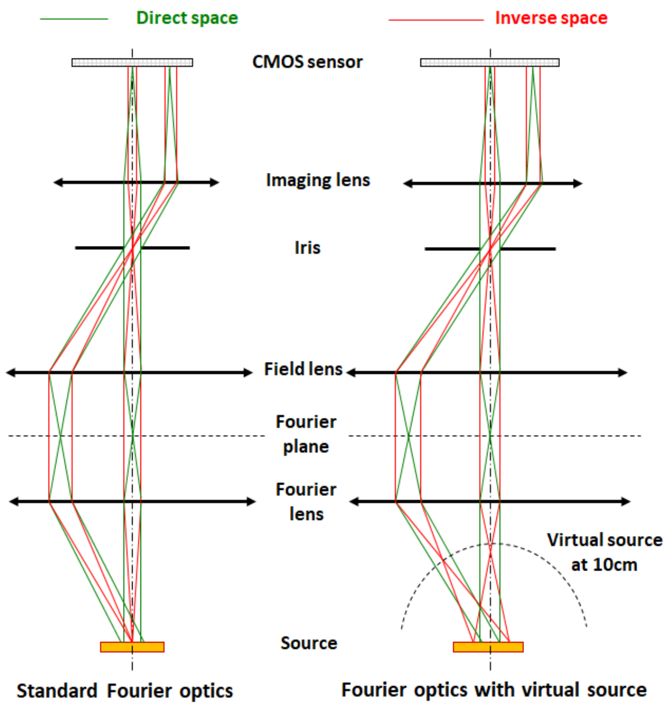

Figure 2. Schematic diagram of a standard Fourier system and a Fourier system with virtual source at 10cm

Fourier optics for source characterization: The requirements are different when measuring small size light sources. The cosine compensation is not needed but it is necessary to ensure that all the light emitted by the source is collected by the Fourier optics. In addition, to comply the safety regulations, the Fourier optics needs to be working on a virtual source at 10cm of the sample (cf. figure 2.b). This is realized adjusting the optical setup of the Fourier lenses. The new optical system has an angular aperture of ±70° and an angular resolution below 0.05°. The measurement spot size is fixed to 2.2mm and the best working distance to 3mm with some gap in the adjustments both laterally and perpendicularly. Indeed, the measurement results need to be maintained even for a small lateral or perpendicular shift with regards to the perfect theoretical adjustment otherwise the system becomes too difficult to adjust. This type of property has been tested experimentally on our system using a near Lambertian light source with a 2mm diameter (940nm LED diode with a diffuser and a 2mm mask). The angular emission of such source is quite large and covers the angular aperture of the instrument as reported in figure 3.a. With a small translation of the source of ±0.5mm and a defocus of ±50μm the measurement results are maintained within ±2% of the reference curve for the entire angular aperture as shown in figure 3.b.

NIR range and absolute calibration: The imaging detector is a low noise high resolution 12bits CMOS sensor. Its typical spectral responsivity is high in the region of interest (800-1000nm) as shown in figure 4.a. Absolute calibration of the systems is made using reference silicon photodiode calibrated at NIST with an absolute light source (cf. figure 4.b and reference [12]). In the region of interest, the sensitivity of the systems, even if smaller than in the visible range, is enough to reach easily saturation even with low power lasers. The system is then equipped with different density filters to avoid saturation and ensure that the spectral responsivity is flat in the region of interest. The system is also not sensitive to the polarization thanks to the optical design and a good selection of the different components. A measurement time less than 1s allows quality control in good conditions.

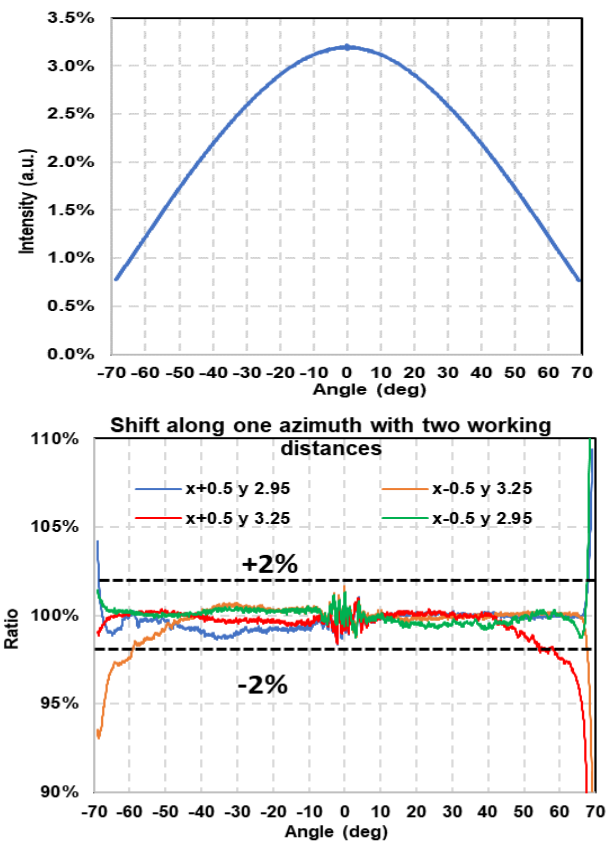

Figure 3. Angular emission of a near Lambertian source at 940nm (top) and its response dependence to lateral shift (±0.5mm) and two working distances (2.95 and 3.25mm) (bottom).

3. Some experimental results

940nm LED: We have measured the emissive properties of one light emitted diode (LED M940F1 from Thorlabs). Its maximum of emission take place around 940nm with a quite large band pass around 70nm. The emissive cone is also quite large and covers the angular aperture of the instrument (cf. figure 5.a). Measurements with different currents injected inside the LED do not change too much the shape of the emissive cone. The emitted power and the maximum of radiance on-axis versus the applied current have been measured. There are reported in figure 5.b and show a good linearity except for very small currents.

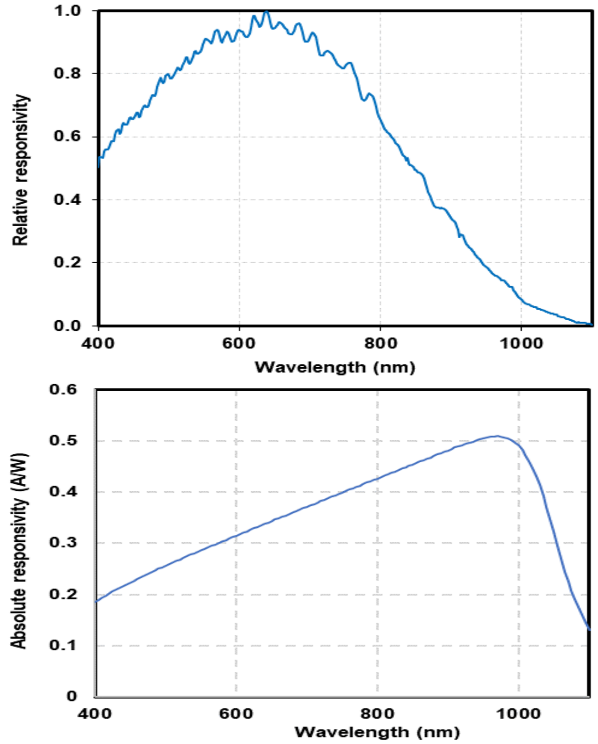

Figure 4. Relative spectral responsivity of a CMOS sensor (top) and absolute spectral responsivity of NIST calibrated Si photodiode (bottom).

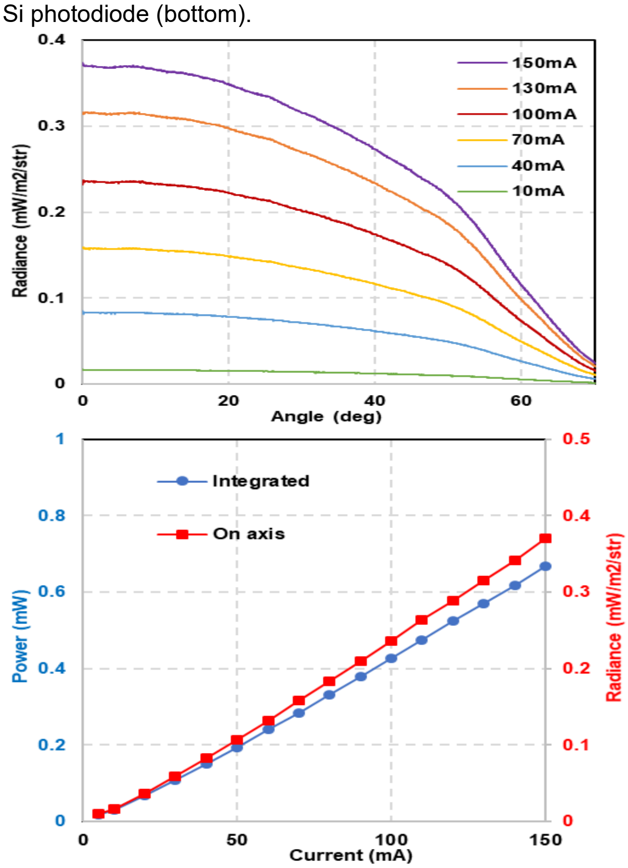

Figure 5. Angular radiance at different currents (top) and power and maximum of radiance versus current measured on a 940nm LED diode (bottom).

940nm VCSEL laser diode: Vertical cavity laser diodes are never perfectly collimated and require additional optics to obtain well collimated beams. In addition, there angular emission can depend strongly on the current and the temperature [13]. It is then necessary to characterize carefully the angular emissive cone of this type of device to optimize the optics. In some simple applications like short range proximity sensors the VCSEL component is used directly as NIR source to perform time of flight sensing. We have measured the emission of the VCSEL of a VL53L1X sensor from ST that allow real time distance measurements up to 400mm. Results are reported in figure 6.a and 6.b. The emissive cone is restricted to ±10°. Most of the light is included in a narrow ring around 5°, a shape classically obtained on standard VCSEL [13]. Some speckle due to the partial coherence of the emission is also detected in all the emissive cone. Another measurement on a VCSEL with additional optics is reported in figures 7. And 7.b. The angular aperture is here enhanced by the optics to allow 3D imaging time of flight measurements.

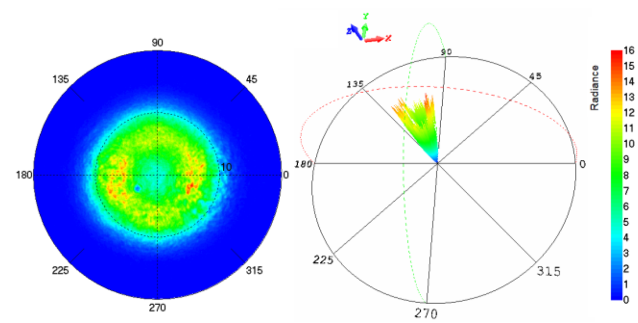

Figure 6. Emission of the 940nm laser diode of a VL53L1X time of flight sensor: angular pattern (left) and 3D representation (right).

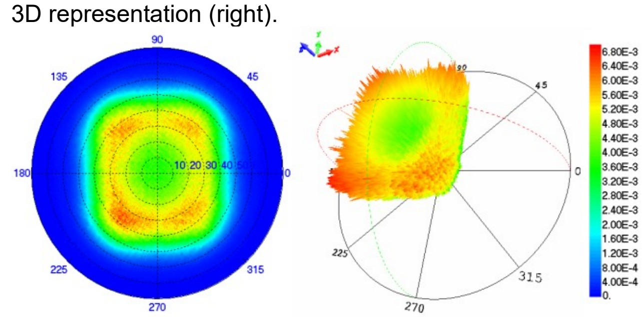

Figure 7. Emission of a 940nm VCSEL with additional optics: angular pattern (left) and 3D representation (right).

Romeo source of IphoneX: As reported in the introduction, IphoneX Face ID is made using a "Romeo" module that projects many infrared dots on the face of the user. This source is constituted by a VCSEL periodic array, coupled to one optics that projects the light on a diffractive element. Each VCSEL produces a light beam along a given direction that is splitted along many directions by the diffractive element. Since the wavelength is relatively stable for the VCSEL (in this case 940nm), the diffractive element works in the same way for all the beams. The diffraction is applied along two orthogonal directions to enhance the emissive angle of the device. The pattern of the VCSEL array is then projected along different directions producing more than 30000 spots in all the directions [14]. One example of measurement is reported in figures 8.a and 8.b. The need of a high angular resolution for such measurements is particularly clear.

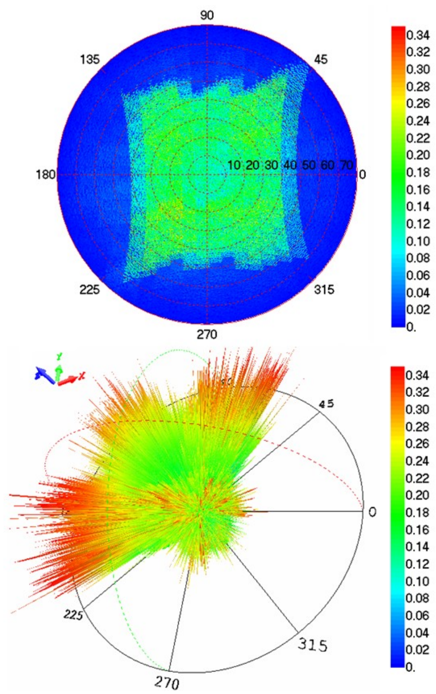

Figure 8. Emission diagram of the face recognition 940nm Romeo source of one IPhoneX: angular pattern (top) and 3D representation (bottom).

4. Conclusions

New Fourier optics instruments dedicated to the characterization of NIR light sources have been presented. With different angular apertures and high angular resolution, there give in real time all the details of the emissive cone of such sources. The system is calibrated in an absolute way and provides directly the radiance and the power emitted by the source. Its physical adjustment it not critical due to the adapted optical design. The acquisition can be synchronized for pulse lasers or controlled independently for continuous ones. The optical setup can be adapted to comply IEC 60825-1 safety regulations. It is also designed to avoid parasitic polarization that can create accuracy problems when measuring VSCELs that are naturally polarized. Examples of measurements on different types of sources have been presented.

5. References

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Table 1. Main characteristics of the ELDIM systems for angular characterization of NIR light sources

Specifications		OFScope NIR	VCProbe NIR
Working distance		30mm	4mm
Viewing angle	Incidence angle	±40°	±70°
	Azimuth angle	0-360°	0-360°
Wavelength		850-940nm	850-940nm
Exposure time	Synchronized for pulsed sources	70µs – 800ms	70µs – 800ms
Measuring area	Entrance Pupil	4mm	2.1mm
Optical setup	Virtual source	10cm or infinity	10cm or infinity
	Optical resolution	0.05°	0.05°
	Optical densities	up to 7	up to 7
Performances	Radiance (w/str/m²)	±2%	±2%
	Integrate power (watt)	±1%	±1%