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Outline for a radiometric unit of measure to characterize SWIR illumination

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Summary:

Imaging in the shortwave infrared (SWIR, 0.9-1.7µm) is increasingly utilized in applications like security or military surveillance, industrial quality control, food and agricultural inspection and it is foreseen to be used in the fast developing market for advanced driver assistance systems (ADAS). All applications suffer from a lack of a standardized SWIR radiometric unit of measure, that can be used to definitely compare or predict SWIR camera performance with respect to SNR and range metrics. We outline the definition of a unit comparable to the photometric illuminance lux unit and show proposals for its implementation.

Keywords: SWIR, swux, InGaAs, radiometry, photometry

SWIR irradiance backgrounds do not consistently track visible-light illumination at all, [1] [2]. Nevertheless, in most system test reports of imaging devices relying on the short wave infrared spectral range, photometric units for the visible light are still used to characterize the illumination conditions. For the SWIR waveband we introduce the implementation of a new unit of illumination measurement, that is spectrally weighted to the standard lattice-matched InGaAs absorption, as proposed first in [1]. InGaAs is still the most commonly used material for SWIR camera sensors.

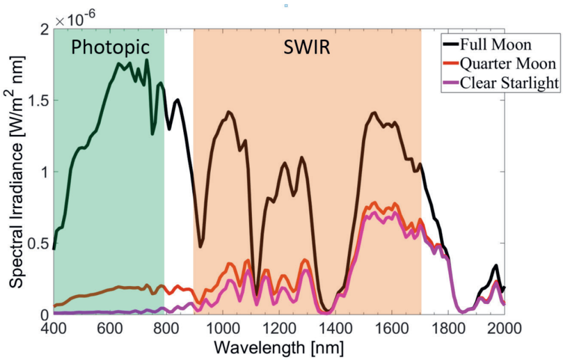

Fig. 1. Typical spectral irradiance levels for selected low light scene conditions, showing the weak correlation between photopic and SWIR specific integrated sensing levels.

This SWIR band specific irradiation unit is termed the swux, short for SWIR lux. The swux unit would be a good choice for characterization of ambient lighting conditions that exist during test trials of SWIR camera systems, particularly at night or limited sight conditions, where human observers tend to severely underestimate ambient SWIR backgrounds based on their subjective visual perception of lighting conditions, see e.g. Fig.1. We propose a method for measurement of ambient SWIR levels, a so-called "swux-meter" that can be constructed from COTS light measurement components and a COTS absorbing glass filter [3]. The intention of the new SWIR-specific spectroradiometric units (based on the idea of an analogous

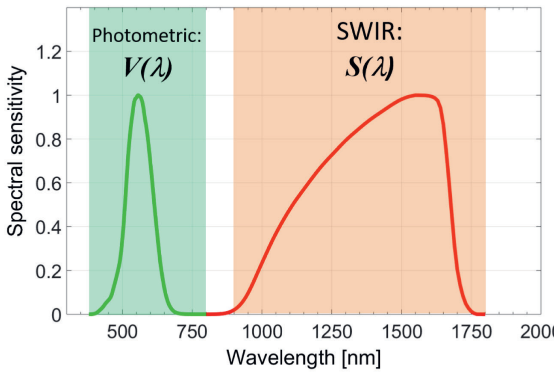

Fig. 2. Comparison of the well known photopic response curve V(λ) used for photometric illumination unit and the proposed SWIR spectral radiant efficiency function for SWIR sensing called S(λ), as defined in [1] and used for the definition of the SWIR specific irradiance unit as shown in Fig. 3.

source-independent SWIR-candela definition) is, to provide a practical integral measure for a unified quantification of SWIR scene illumination conditions that can standardize and improve the performance prediction and comparison of SWIR cameras, most of which have a spectral sensitivity curve in the spectral band between 0.9µm and 1.7µm. For the definition of the SWIR specific radiometric units of measure we follow the framework for definition of detector-based photometric scales in Ref. [6]. First a source independent SWIR-candela is proposed as the radiant intensity, in a given direction, of a source that emits monochromatic radiation of frequency 193.413x10^{12} Hz (λ =1.55µm in vacuum), with a radiant intensity in that direction of *sc* watt per steradian, where *sc* = (1/210,000) by definition. Based on this scaling factor the SWIR-specific integral irradiance unit swux can be defined as shown in the following Fig. 3, based on the weighting of the perceived irradiance $E_e(\lambda)$ with the $S(\lambda)$ curve. This constitutes an averaged response of standard lattice matched InGaAs which is shaped on the shortwave end of the band, to compensate for variations in backside substrate processing. A detailed listing of the $S(\lambda)$ values is provided in Ref.[1].

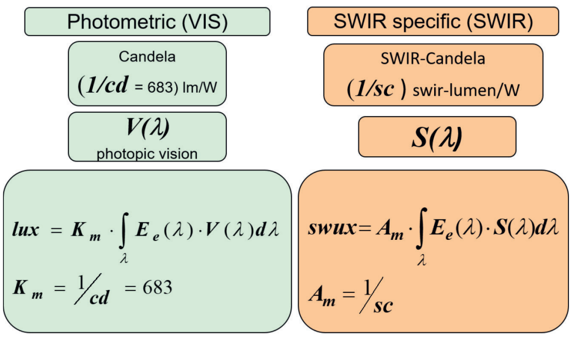

Fig. 3. Analog definition of the SWIR specific irradiance unit of measure compared with the photometric unit of illuminance. The SWIR spectral radiant efficiency function for SWIR sensing S(λ) is shown in Fig. 2.

Based on the defined scaling factor A_m = 2.1E+5 (W/sr)$^{-1}$ resulting from the definition of the corresponding SWIR-candela unit in Fig. 3, the calculated swux levels in Tab. 1 show that a unity swux irradiance level indicates the low light sensing limit for all currently available low light imaging technologies like Gen-3 image intensifier tubes, EMCCD, sCMOS and the highest grade of SWIR cameras. Up to 7 orders of magnitude in swux level are covered from natural scene irradiance levels up to direct sunlight illumination.

Tab. 1: Selected reference spectral scene irradiance distributions from NVESD SSCamIP 2009.

Illumination condition:	Swux level	Lux level
Overcast starlight	3.8	1.2E-4
Clear starlight	38	1.2E-3
Quarter Moon	44	1.1E-02
Full Moon	97	0.1
Overcast daylight	4.6E+04	900
Direct sunlight	2.8E+07	8.8E+4

We started several implementations of swux-meters both as portable devices enabling field based scene measurements [3] and in radiometric test benches [4], [5], where the minimum receivable contrast of a SWIR camera can be measured in dependence of the corresponding swux-level, thus making predictions on the field performance of the tested cameras in real life applications possible.

To become established among all users in the fields of relevant SWIR camera applications, the traceability of the new swux unit would have to be established by relevant standardization institutions. An agreement on how to realize the proposed SWIR-candela is necessary. For these purposes it would be very useful to extend the definition of the broad band CIE standard Illuminant A [7] beyond 820nm, including the SWIR spectral range until at least 1800nm, as described in Ref. [1].

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