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Personnel real time dosimetry in interventional radiology

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ABSTRACT

Interventional radiology and hemodynamic procedures have rapidly grown in number in the past decade, increasing the importance of personnel dosimetry not only for patients but also for medical staff. The optimization of the absorbed dose during operations is one of the goals that fostered the development of real-time dosimetric systems. Indeed, introducing proper procedure optimization, like correlating dose rate measurements with medical staff position inside the operating room, the absorbed dose could be reduced. Real-time dose measurements would greatly facilitate this task through real-time monitoring and automatic data recording. Besides real-time dose monitoring could allow automatic data recording. In this work, we will describe the calibration and validation of a wireless real-time prototype dosimeter based on a new sensor device (CMOS imager). The validation measurement campaign in clinical conditions has demonstrated the prototype capability of measuring dose-rates with a frequency in the range of few Hz, and an uncertainty smaller than 10%.

1. Introduction

In the past decades, the number of interventional radiology procedures has increased steadily, raising some concerns about the absorbed ionizing radiation levels by medical staff. Since the surgeon and radiologists are not always wearing protective glasses or gloves, the radiation diffused by the patient's body may present a problem especially to their extremities and eye lenses (see for example [1]). In the framework of the ORAMED project (Optimization of Radiation Protection in Medical Staff) a focused study on how to mitigate this problem started [2]. Many other studies have been carried out on the effects of such exposure mainly on the eye lens [3–6], leading to a revision of the ICRP recommended exposure levels [7]. Several surveys on the average levels of absorbed dose related to the type of procedures and the correct ways of measuring them have also been done [8–13]. Furthermore, many studies on the reduction of the exposure obtainable with additional shields, education of the medical staff or modification of the medical procedures are available [14–16].

The self-education of operators is the most efficient way to reduce the absorbed dose during a single operation by changing the procedures if possible. This requirement is often difficult to perform using passive dosimeters. Actually with this solution the dose is integrated over a period of 1–2 months, making it impossible to correlate the peaks of irradiation with specific activities during a single procedure. Active Personal Dosimeters (APD) have been developed to attain this goal; in the ORAMED project a series of active dosimeters have been studied comparatively to understand their characteristics [17–19], and also other studies have been done when new devices became available [20,21]. The results of these studies show that active dosimeters could be useful for medical staff self-training, even if there are some problems related mainly to the different response to different regimes of use of the X-ray system (pulsed vs. continuous mode, fluoroscopy vs. fluorography, angular efficiency) and to their wearability or presence of cables.

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In this framework, the RAPID project (Real-time Active Pixel Dosimeter), financed by Istituto Nazionale di Fisica Nucleare, was launched, aiming at the development of a new type of APD, completely wireless, and capable of working in the full range of clinical conditions of interventional radiology procedures with a dose rate measurement precision of the order of 5% [29]. In Table 1 are reported the most diffused APDs with their key features as a reference for comparison with those of our APD. Here is briefly described the RAPID prototype, the calibration procedure, and the obtained results during an extensive validation campaign in clinical conditions. In more than 40 procedures the prototype has been worn by medical staff together with passive dosimeters (TLD) for comparison with a certified dose.

2. Material and methods

The RAPID wireless prototypes, RAPID-1 and RAPID-2, are described in detail in [30,31]. They mount the same sensing element and differ mostly in the integration level of all the components and their wearability. The main difference is the presence in RAPID-1 of a dipole antenna 17 cm long, while RAPID-2 has the antenna implemented on the printed circuit board, thus reducing the prototype dimensions to $10 \times 5 \times 2$ cm^3 (Fig. 1). Hence, the operator could wear RAPID-2 prototype not only on the chest over the apron but also on the arms. The wireless transmission could operate using both frequencies reserved for medical devices in EU or USA, 868 and 915 MHz respectively. Both prototypes use as sensor element a CMOS VGA imager (MT9V011), with an area 3.5×2.5 mm^2, sensitive from few keV up to 150 keV photons. The thickness of the epitaxial layer is ~5 µm with a total sensitive volume of 0.0017 mm^3. The readout frequency is 5 Hz (5 frames/s), with a CPLD (Complex Programmable Logic Device) on board for real-time data reduction and a microcontroller. The devices can operate continuously with four (RAPID1) or three (RAPID2) rechargeable AAA batteries for more than 8 h. The transmitted data are recorded in a file as a trace formed by records containing for each single RAPID device, the information related to a single frame, among which its identification label, the frame timestamp, and the dosimetric observables.

Many papers in the last decade (see for example [32,33]) demonstrated the possibility to use CMOS imagers, optimized for visible light collection, as X-ray detectors. This property relies on the large signal/noise ratio (~30–40) due to photon interaction in the sensitive layer of the device. Because of the very small sensitive volume dimensions of each pixel ($\sim 5 \times 5 \times 5 \mu$ m^3), a single photon generates a signal on just a small cluster of pixels centered on the pixel containing the electron–hole creation point. Hence,

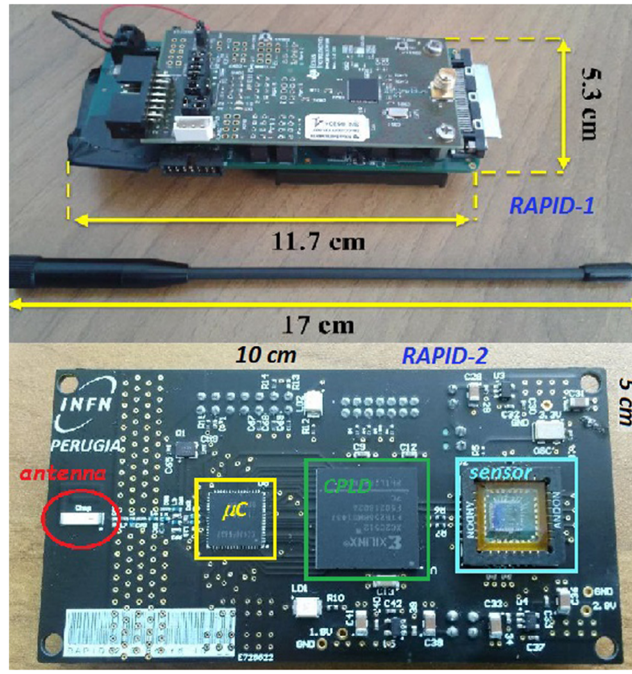

Fig. 1. Upper photo: Prototype RAPID-1. The batteries (four 1.5 AAA) are hosted on the back of the prototype. Dimensions are: $17 \times 5.3 \times 5$ cm. Lower Photo: prototype RAPID-2: from left to right: wireless antenna (red), microcontroller (yellow), CPLD (green), sensor case (cyan). The batteries (three 1.5 AAA) are hosted on the back of the prototype. When working as dosimeter element, the CMOS imager is optically blinded. Dimensions are $10 \times 5 \times 2$ cm. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

isolation of each photon signal inside the pixel matrix is possible until the photon flux increases over 0.05 interacting photons/pixel/frame, as extracted from [34]. In our case, this number corresponds to a dose rate of ~300 µGy/s.

The number of pixels forming a cluster depends linearly on the incoming photon energy hence it is possible to use the sum of the pixels belonging to clusters in a frame (N_F) as a dosimetric variable for the dose rate [35]. Another possible dosimetric variable is the sum of the signal over all the pixels belonging to the clusters in a frame (E_F). Because the signal of each pixel is linearly dependent on the energy of the incoming photon, this variable could be used to have a better correlation for high fluxes where some superposition among clusters start to be non-negligible [35].

The diffused photon spectra have been measured exposing a phantom made of PMMA slabs ($30 \times 30 \times 30$ cm) to beams

Table 1
Characteristics of commercial Active Personal Dosimeters

Dosimeter	Energy range	Personal dose equivalent range (Hp(10))	Personal dose equivalent rate range (Hp(10)/s)	Angular response [22]
[23] MGPi DMC2000XB	20 keV 6 MeV	1 µSv 10 Sv	0.1 µSv/h 10 Sv/h	Compliant
[24] Thermo Scientific EPD-Mk2+	15 keV 10 MeV	0 µSv 16 Sv	0 µSv/h 4 Sv/h	Compliant
[25]Dosilab EDM-III	20 keV 6 MeV	0.1 µSv 1 Sv	0.5 µSv/h 1 Sv/h	Compliant
[26] UNFORS EDD-30	14 keV 120 keV	0.01 µSv 9999 Sv	30 µSv/h 2 Sv/h	Spherical
[27] Atomtex AT3509C	15 keV 10 MeV	1 µSv 10 Sv	0.1 µSv/h 5 Sv/h	Compliant
[28] Philips DoseAware	33 keV 118 keV	1 µSv 10 Sv	40 µSv/h 150 mSv/h	Compliant

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