Characterization of wireless personal dosimeter prototype for Interventional Radiology medical operators

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I. INTRODUCTION

- Interventional Radiology (IR) is a minimally invasive diagnostic and therapeutic procedures performed using radiological devices to obtain image guidance:
  - high levels of exposure of patients and medical staff to X-rays can induce detrimental effects
  - international guidelines in radiation protection restrict the number of procedures that operators can undertake [*NCRP 133*].
- External monitoring is currently acquired through passive personal dosimeters [effective dose (whole body) and equivalent dose (hands, arms, legs,…)]

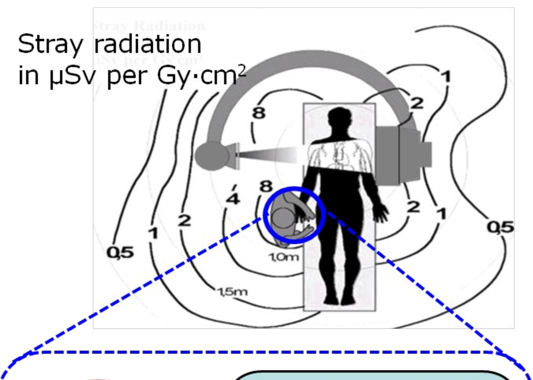
Passive dosimeter	Energy range (keV)	Dose range
TLD	10 – 3000	$5 \cdot 10^{-4} – 10^{3}$ Gy
Film dosimeter	10 – 3000	$40 \cdot 10^{-3}$ – 1 Sv

- The authors present the characterization and calibration of a wireless dosimeter prototype to perform on line monitoring of the staff during interventional procedures, by using a CMOS Active Pixel Sensor as radiation detector.

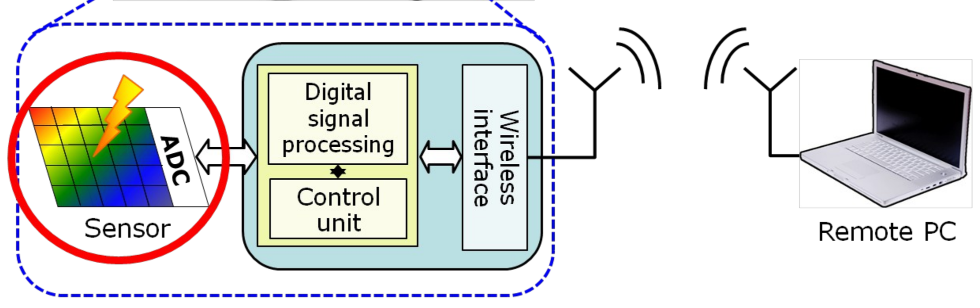
II. THE ACTIVE PERSONAL DOSIMETER

- Main features of the commercially available active personal dosimeters:
  - semiconductor technology
  - real-time evaluation of dose and/or dose rate
  - alarm at a pre-set dose and/or dose rate < level (opt.).

  Performance is not satisfactory for X-ray fields used in IR procedures (low energies and pulsed fields) [*Villani, 2013*]. With pulsed X-ray beams the response decreases:
  - as the dose equivalent rate increases
  - from 10 to 40% when pulse rate increases from 1 to 20 pps.
- We propose a device based on an Active Pixel Sensor (APS) based on the following requirements:
  - sensitivity from 5 to several tens of keV photons (X-ray) dose and dose rate measurement accuracy better than 10%
  - wireless device
  - small form factor and lightweight (wearable).

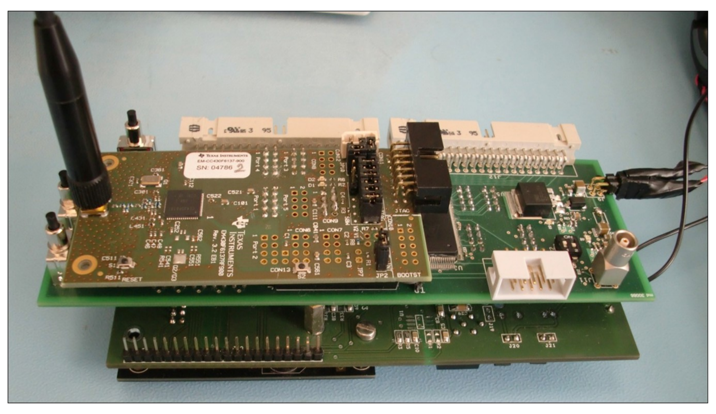


- System architecture:
  - Sensor
  - Digital signal processing unit
  - Control unit
  - Wireless interface
  - Graphical user interface.



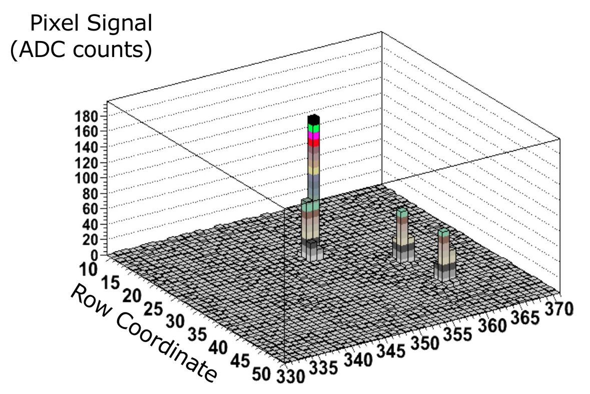
III. THE DOSIMETER PROTOTYPE RAPID-0

- A first dosimeter prototype, RAPID-0, has been constructed using commercial components (sensor board, microcontroller with wireless module) and a custom board where are hosted the CPLD for data elaboration and services.
- CMOS image sensors can be used as ionizing radiation detectors *[Servoli, 2012]*.

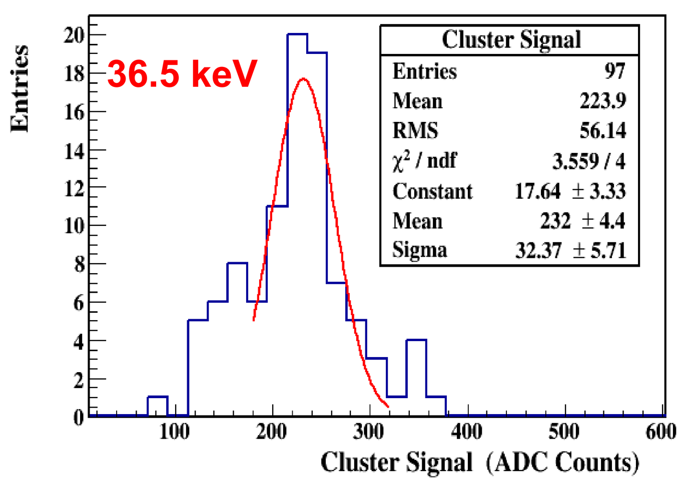


- The selected sensor (11.43 x 11.43 mm² package form factor) is a standard VGA (640 x 480 pixels), 5.6 x 5.6 µm² pixel size, optimized for 30 fps.

IV. THE CALIBRATION PROCEDURE



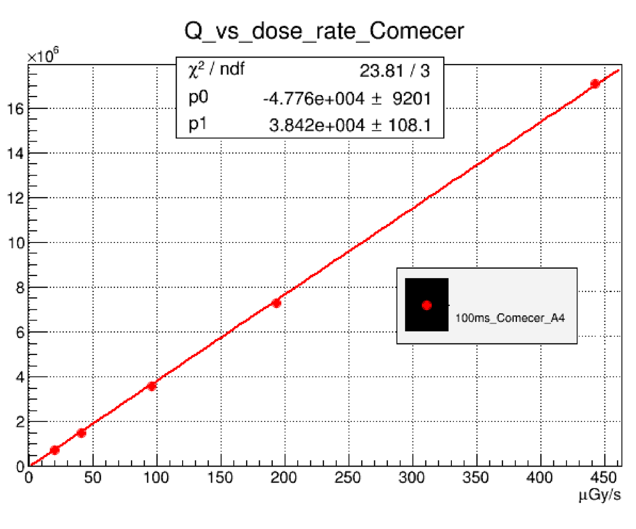
- Photon detection is carried out by using a clustering algorithm to reconstruct the photon energy grouping all the pixels where the signal has been divided.
- Only a limited number of pixels shares the signal generated by the photon with a weak dependence from photon energy, in the tens of keV range.
- Single photon identification can thus be used to measure the photon flux.
- The sensor response to the X-ray radiation has been calibrated using monochromatic (fluorescence) or quasi-monochromatic (transmission) photon beams.
- The calibration coefficient is knows with a precision better than 5%.



The sensor has been exposed to a certified X-ray beam, with energy spectrum similar to the one diffused during Interventional Radiology procedures.

A dose rate up to 450 µGy/s has been delivered, more than the most demanding IR procedures.

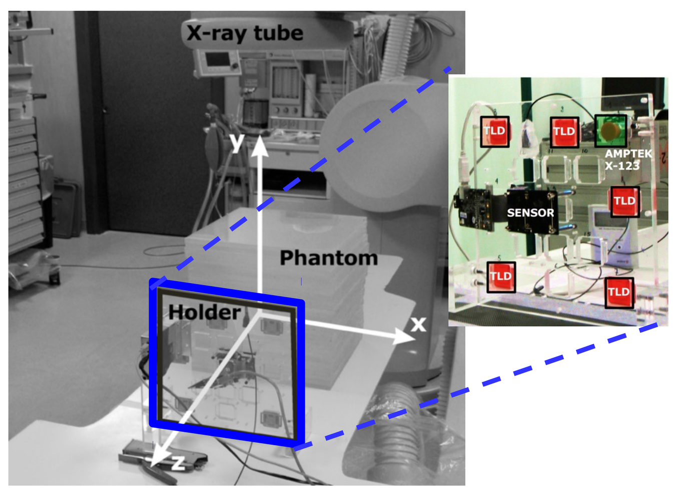
The Dose Rate and the Signal over a frame (Q) are linearly correlated with an error of ~ 1%.



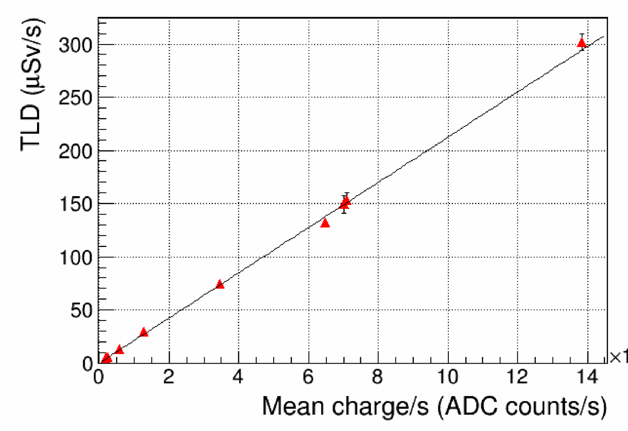
V. TEST WITH DIFFUSED X-RAYS

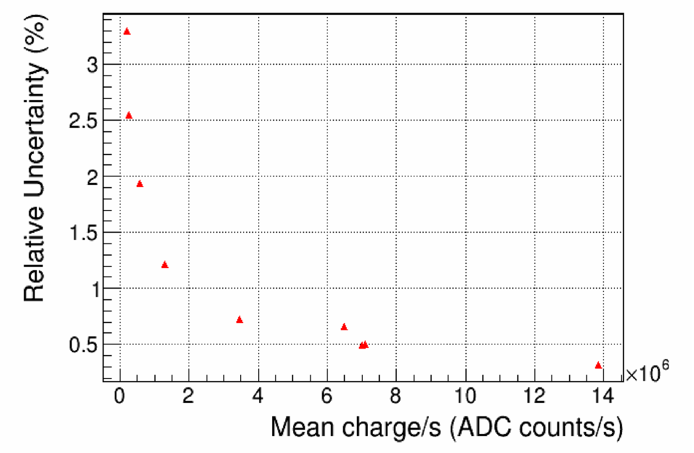
A plastic holder with sensors, TLDs, and a spectrometer has been positioned to collect X-ray photons diffused by a phantom made of PMMA slabs.

All the most common Interventional Radiology procedures have been performed to check the validity of the prototype in all conditions.

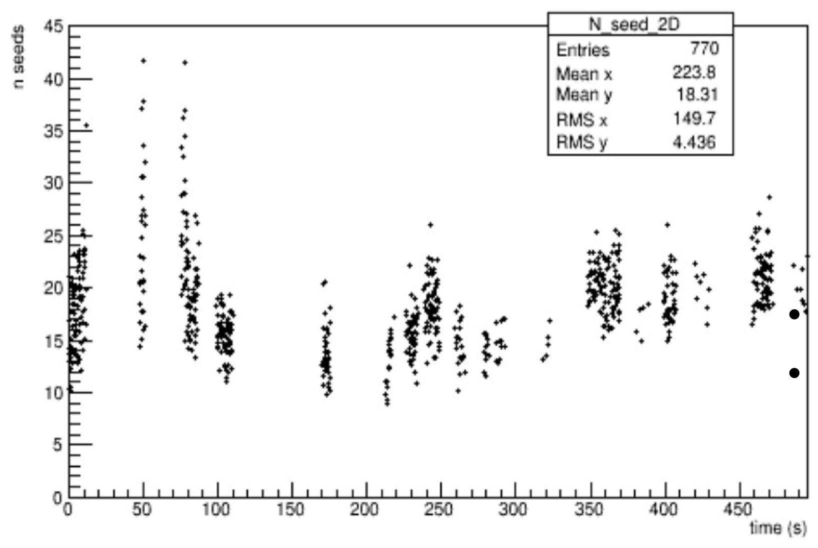


Two system observables to be used as dosimetric quantities have been defined: the ***number of detected photons*** and the ***mean charge per second*** (i.e. the sum of the reconstructed photon signals per second over a frame).





Both dosimetric observables are linear with respect to the measured dose and dose rate with independent dosimeters, and the relative uncertainty is below 5% for all dose rates.

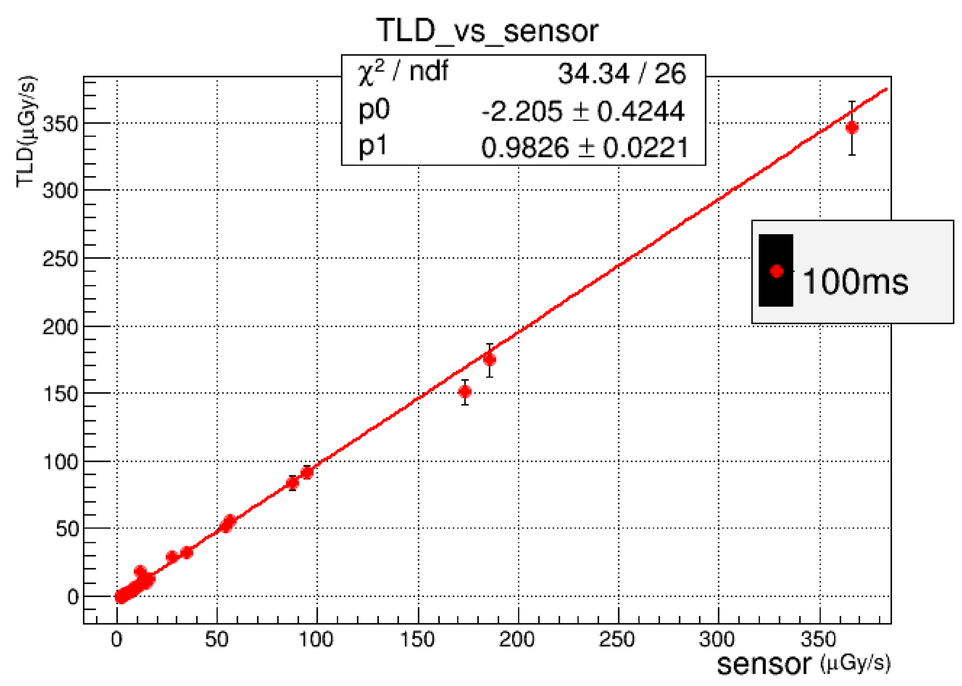


The prototype has also been tested in real Interventional Radiology procedures. The 10 Hz acquisition rate allows to follow closely the X-ray tube operations.

A precise monitoring of the absorbed dose during the procedure hence become possible.

Both dosimetric observables, the number of photons and the Signal over a frame shows a linear correlation with measured dose by TLD.

After applying calibrations obtained with certified X-ray beams, ***the dose and dose rate read out by the prototype are within 2% of the dose read by the TLD dosimeters.***



VI. CONCLUSIONS

- A novel approach to perform on line monitoring of the staff during interventional procedures by using a device based on a CMOS APS has been proposed.
- The sensor performance as an X-ray radiation detector has been evaluated with a dedicated experimental set-up.
- Two dosimetric observables have been assessed from the frames acquired by the sensor using a clustering algorithm.
- Two different dosimetric quantities being compatible with the real time requirements have been defined from a subset of the collected data.

References

- [NCRP 133] National Council on Radiation Protection and Measurement, NCRP, "**Radiation protection for procedures performed outside the radiology department**", *2000, Publication 133.*
- [Villani, 2013] E.G. Villani et al., "**Monolithic 180 nm CMOS Dosimeter for In Vivo Medical Applications,**" *IEEE Transaction on Instrumentation and Measurement*, vol. 60, no. 2, pp. 843-849, Apr. 2013.
- [Servoli, 2012] L. Servoli et al., " **An active pixel sensor to detect diffused X-ray during Interventional Radiology procedure**". *Journ. of Instr. 7 P04004 (2012) 000-011*

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