Use of a commercial CMOS-sensor in radiation detection and measurement

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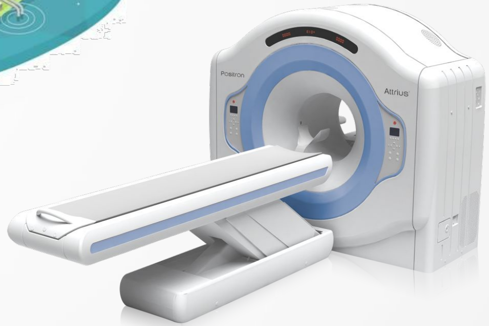
Radiation detection applications

- Radiation detectors have many applications in fields such as:
    - Particle physics
    - Medical imaging
    - Nuclear energy
    - Radiation safety



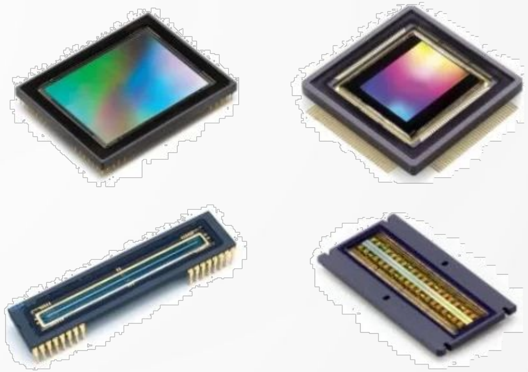
The need for economical radiation detectors

- Despite the numerous fields and their applications even entry-level radiation detectors often cost several hundred euros, limiting accessibility for education, research, and hobbyist use

➔ This highlights a clear and growing need for affordable, reliable alternatives

Semiconductor Detectors (SD)

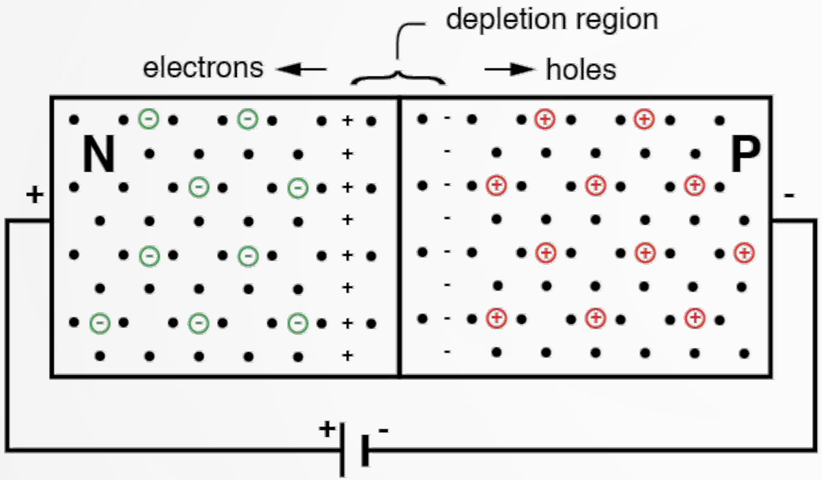
- Recent advancements in the semiconductor industry have increased the popularity of semiconductor-based radiation detectors.
- Common SDs include:
  - Charge-coupled devices (CCD)
  - Silicon drift detectors (SDD)
  - Complementary Metal-Oxide-Semiconductor (CMOS) sensors

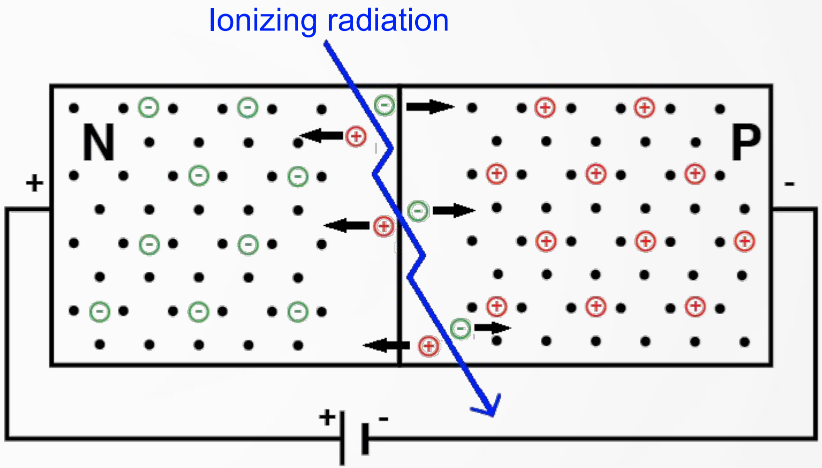


Working principle of SDs

- Semiconductor sensors, like most semiconductor electronics, operate by joining two oppositely “charged” semiconductor materials together, forming a p-n junction
- In SDs, the p-n junction is operated under reverse bias, which widens the depletion region (also known as the active region in SDs)
- Ionizing radiation passing through this region generates electron-hole pairs
  - ➔ These charge carriers are separated by the electric field, producing a measurable electrical signal

P-N junction in reverse bias operation

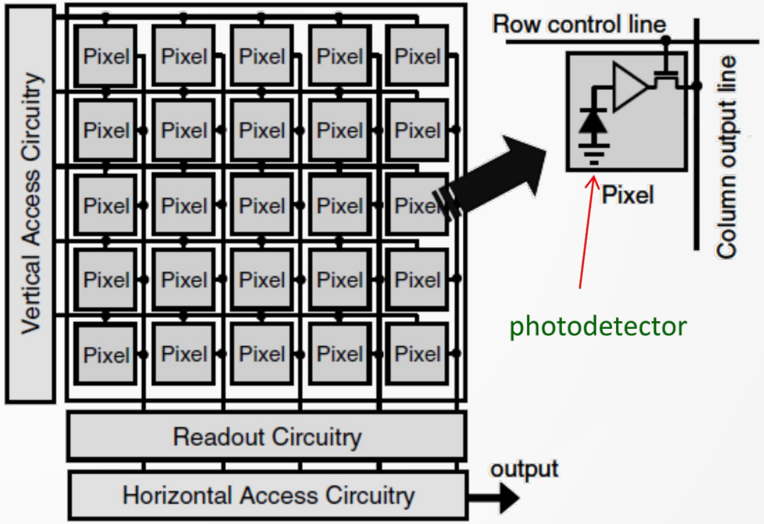




CMOS sensors

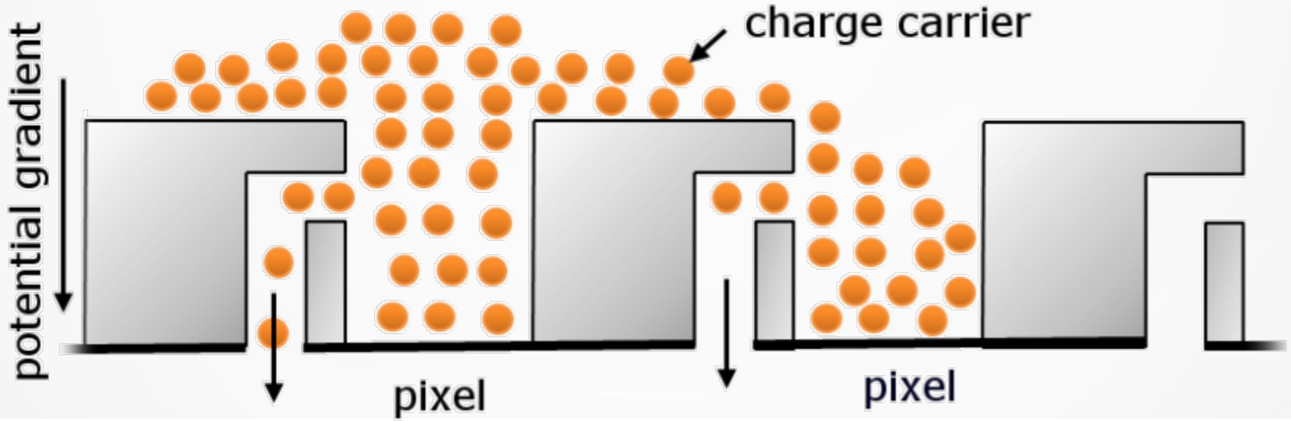
- Popularized by their adoption in consumer electronics
- Properties of CMOS sensors:
  - Active-Pixel Sensor (APS)
  - Low operating voltage
  - Pixel saturation or “blooming”
  - Worse signal-to-noise ratio (SNR) compared to CCDs

CMOS sensor layout



Blooming in CMOS sensors

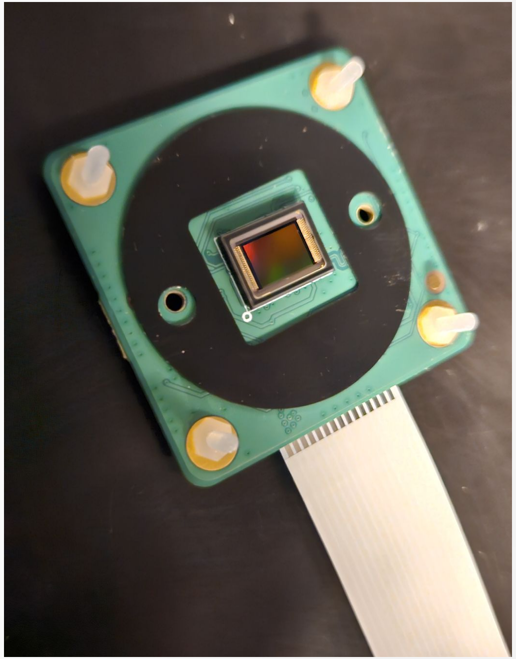
- Highly energetic particles can deposit so much energy in a pixel that the resulting charge overflows into neighboring pixels
  - ➔ If the particle is fully absorbed, its total energy can still be estimated by summing the signal from the affected pixel and its neighbors



Sensor overview: Raspberry Pi HQ Camera

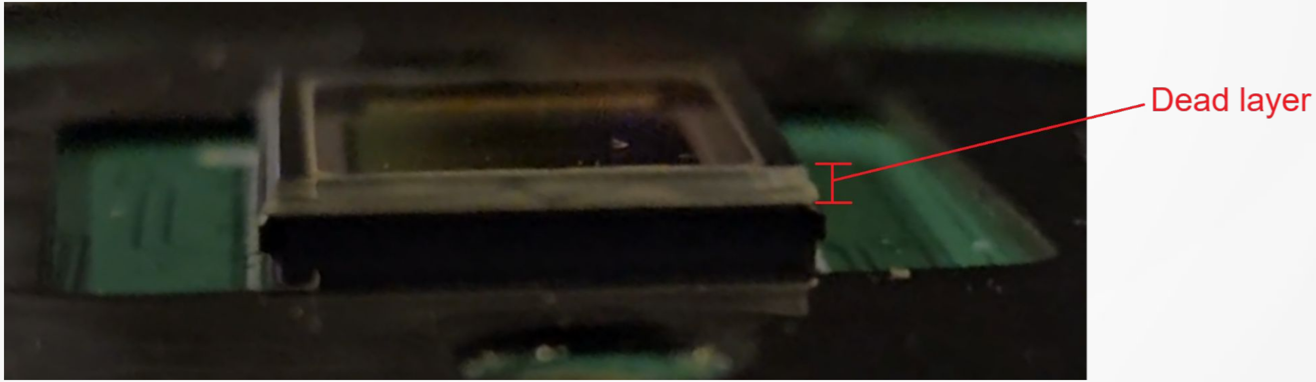
- The sensor was chosen for its commercial availability, low cost and extensive code libraries
- Sensor specifications:
  - Sensor size: 7.5 mm × 5.5 mm
  - Pixel size: 1.55 μm × 1.55 μm
  - Resolution: 4056 × 3040 pixels
  - Sensor thickness: ~ 100 μm

Image from Raspberry PI product page



Sensor “dead layer”

- The sensor is covered by a ~1mm protective glass layer, which blocks alpha particles completely
- Beta (electrons) particles and gamma rays can still penetrate this layer and be detected effectively



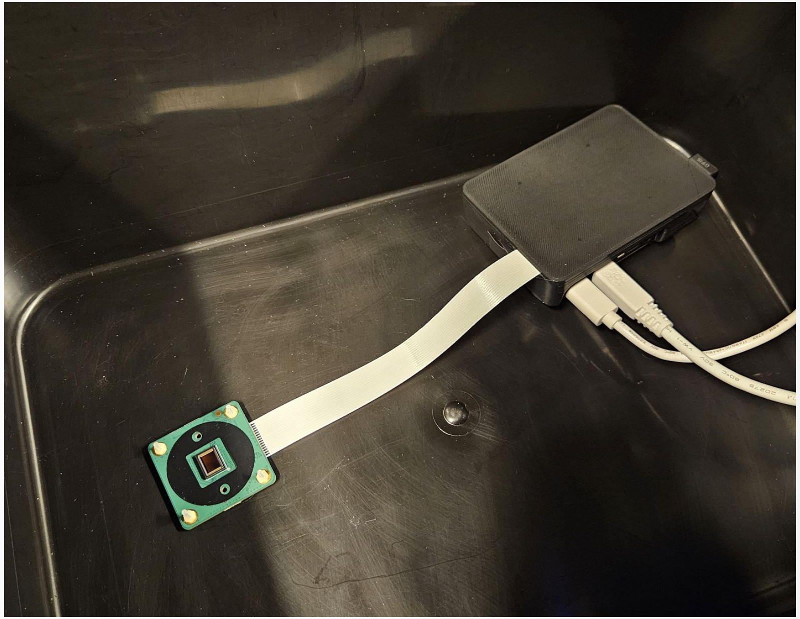
First radiation detection test

- The first tests of the sensor’s radiation detecting capabilities were performed by holding a test source (Fe-55) directly on top of the sensor inside a dark room and observing the image feed:
  - We were able to observe tiny flickering dots in the image that disappeared as the source was moved away from the sensor

    ➔ This confirmed that the sensor was responding to ionizing radiation

Data collection test setup

- The sensor was placed inside a dark box and a small tray with an opening was placed on top of the sensor
- Three sources (Am-241, Ba-133 and Cs-137) were tested, one at a time:
  - Each source was placed on the tray, and images were captured with a 10-second exposure time
  - These images are shown in the next slides



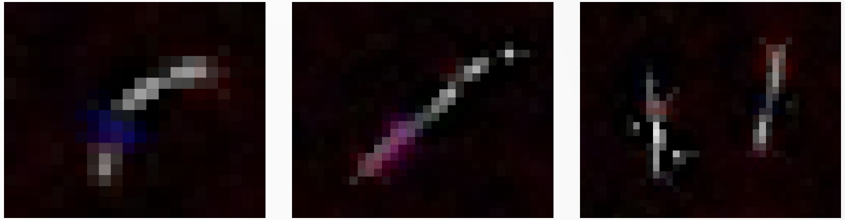
Americium-241

Barium-133

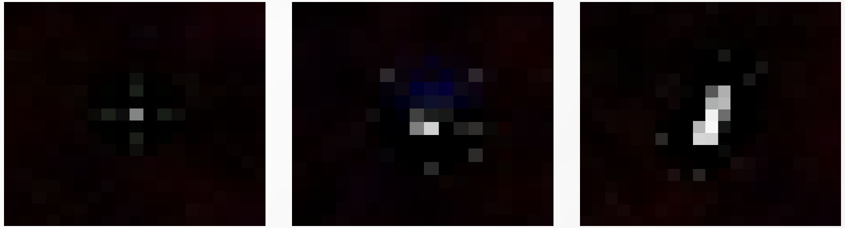
Cesium-137

Preliminary Results

- The images show clear detections of beta and gamma particles
- The dead layer prevents the detection of alpha particles
- The number of hits roughly correlate with source activities
  - At least with Am-241 and Ba-133, the electron trails make Cs-137 hit counts difficult to estimate



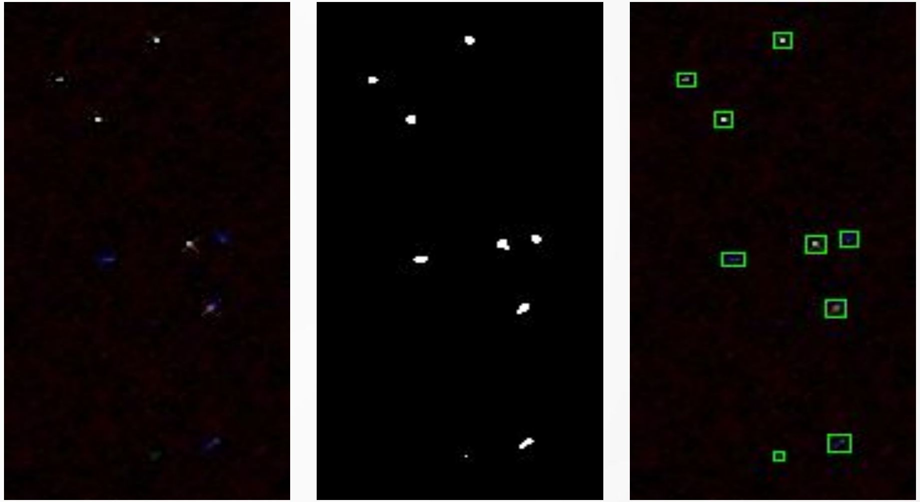
Electron trails from Cs-137



Gamma particles of varying energies from Ba-133

Analysis (work in progress)

- The image data analysis is performed using the OpenCV python library
- Here is an example of how the hit counts were estimated from the images
  - Estimating deposited energies from these counts should be straightforward



Starting image | Gaussian threshold | Connected components

Conclusions

- The CMOS sensor shows promise as low-cost radiation detector
- To fully assess the sensor’s energy measurement capabilities, further analysis is required
- Future experiments could explore whether the sensor’s image-sensing capability can be combined with radiation detection to determine the radiation's point of origin

Thank you for listening!

References

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Lin, J., Wang, F., Wang, J. et al. An investigation of γ radiation detection with a CMOS imaging sensor. Sci Rep 14, 23399 (2024). https://doi.org/10.1038/s41598-024-75096-8

L. Servoli et al. . Use of a standard CMOS imager as position detector for charged particles , Nucl. Instr. and Meth. A 215 (2011) 228-231, 10.1016/j.nuclphysbps.2011.04.016

Megat Harun Al Rashid Megat Ahmad . Detection of ionizing radiations using CMOS sensor from consumer camera device. Chapter 1: The gamma radiation. TechRxiv. May 31, 2023.

Image references

Slide 3: PET scanner image from Positron's product page

Slide 5: Top image from AmpTek product page and Bottom image from Teledyne DALSA

Slide 7: Modified from:
https://www.allaboutcircuits.com/textbook/semiconductors/chpt-2/the-p-n-junction/

Slides 8 & 9: "Application of CMOS sensors in radiation detection", S. Ashrafi, url=https://particles.ipm.ac.ir/conferences/2018/dae/pdf/Ashrafi.pdf