GeigerCam: Measuring Radioactivity with Webcams

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Introduction

Measurement of Radioactivity
Measuring radioactivity has a long history and innumerable academic and commercial applications in nuclear safety, defence, medicine, biology, material sciences, etc. Even entry-level devices start in the $200-300 range which is too expensive for casual applications or mass deployment. The wide field of applications and the public interest, spurred by recent events, make the development of a low-cost device very desirable.

Webcams
The rapid development in image sensor technology and their mass application resulted in cheap meagapixel sensors with highly sensitive pixels to compensate their small size of only 2-3 μm.

Radioactivity and Webcams
We show that only a minor modification to the imaging sensor is necessary to transform a $20-30 webcam into a radioactivity detector with surprisingly large capabilities. In contrast to standard devices such as Geiger counters, our approach can also classify the type of radiation and possible be used for radioactive material identification.

Applications

Consumer hardware
Due to the low cost of both webcams and our modification, it is possible to make radioactivity detectors available to the general population. They can be sold as consumer hardware or mass dispersed in the case of nuclear accidents.

Educational devices
Even with tight budgets, educational institutions can provide on-hand experience on the topic of radioactivity to their students.

Disposable sensors
In adverse environment the use (and inevitable fail) of ionizing radiation detectors incurs a great cost. Our solution would provide cheap sensors for one-time useage. This has application in science, nuclear safety, defense and space technology.

Hardware Modifications

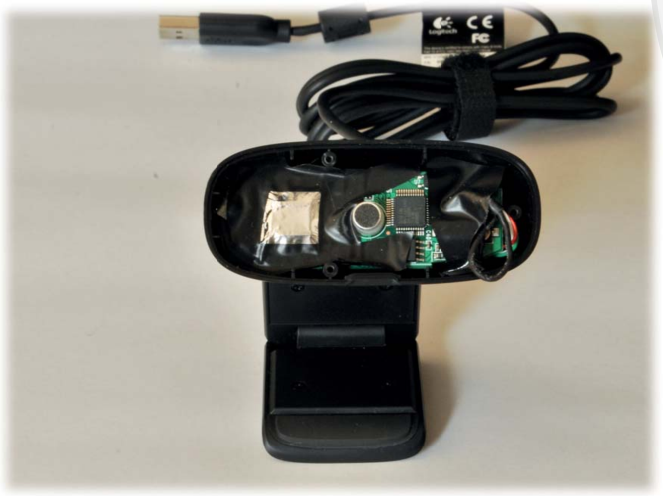
We use a low-cost Logitech C270 HD Webcam and remove all components in front of the imaging sensor as they would absorb all α particles, and β particles to a large degree. This constitutes both the lens and the infrared filter.

Original camera

Due to the partly very faint signals of the particle impacts we want to measure, we operate the camera with extreme exposure and gain values. Visible light completely saturates the sensor at these settings and makes it impossible to measure the much weaker signal of the particle impacts.

Lens and infrared filter removed

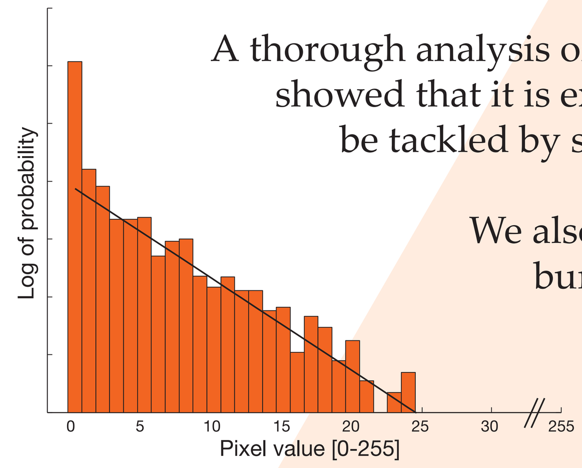
To optically insulate the sensor we cover it with 8 μm thick aluminum foil. This is sufficient to block all incoming light and at the same time thin enough to let α particles pass in sufficient quantities. Aluminum is also highly reflective in the infrared range and thus serves as substitution for the infrared filter that was removed before.



Aluminum foil applied

Software

After the hardware modification has removed optical and thermal radiation noise, the imaging sensor still exhibits thermal and electronic device noise. To improve the signal-to-noise-ratio we use real-time image processing on the direct video feed of the camera.

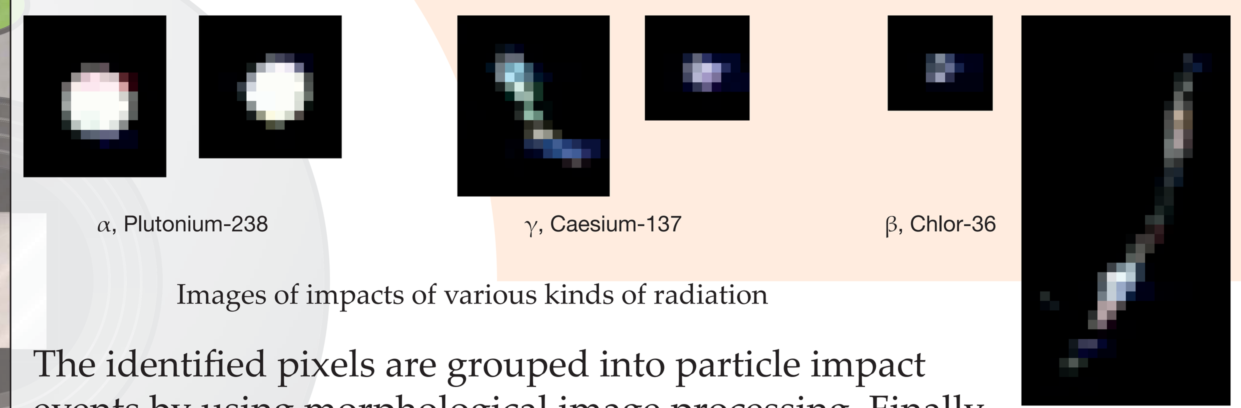


Noise distribution

A thorough analysis of the per-pixel background noise showed that it is exponentially distributed and can thus be tackled by single exponential smoothing.

We also encountered frequent single pixel burst, where just a single pixel exhibits an above-noise value for a single frame. We attribute this to noise of both the sensor and the read-out electronics, and remove it by convoluting each frame with a ring filter.

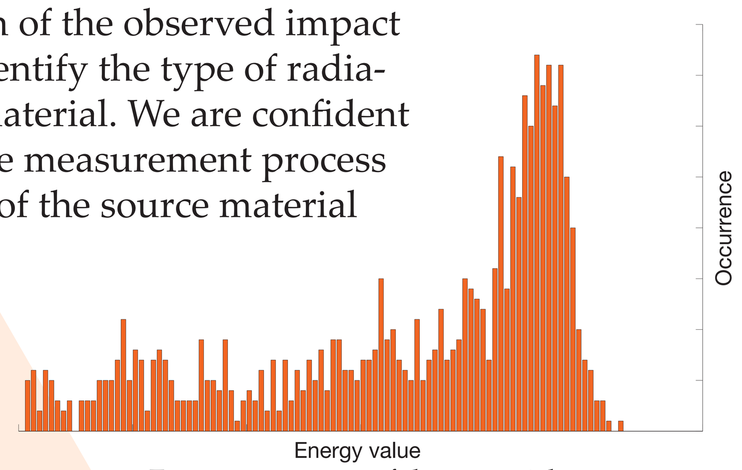
For each frame a per-pixel confidence value is calculated to identify potetially hit pixels. We obtain it by multiplying the per-pixel probabilities of being hit before and after the convolution. A thresholding operation is sufficient to get a clean image that serves as input to our analysis step.



Images of impacts of various kinds of radiation

The identified pixels are grouped into particle impact events by using morphological image processing. Finally a energy for each impact is calculated in linear color space. This allows us to store only the relevant part fo the signal data for later in-depth analysis. Our program is implemented in Matlab and we use the GPU for the data intensive matrix calculations. All the beforementioned steps run in real time.

The final output is the number of measured impact events and their respective energies. The former value gives the radioactivity of the source material by multiplying it with the device's calibration factor, which has to be determined beforehand. The latter value can be used to generate a histogram of the observed impact energies, which allows to identify the type of radiation emitted by the source material. We are confident that further refinement of the measurement process will allow the identification of the source material itself.



Energy spectrum of the α particles emitted by Americium-241

Measurements

We measured a wide range of calibrated radioactive samples as well as freely available and natural sources.

Type	Samples	Natural sources
α	Americium-241, Plutonium-238, Plutonium-239, Uranium-233	Pitchblende (Uranium-238), Gas mantles (Thorium-232)
β	Carbon-14, Chlorine-36, Strontium-90	Tritium illumination (Hydrogen-3)
γ	Cobalt-60, Caesium-137	
n	Plutonium-Beryllium	

Measured materials

The α and β samples were measured at a fixed distance and our reference device was a *Berthold LB 124 SCINT*. To evaluate the γ detection capabilities of our device we used a strong Caesium-137 source and measured at various distances, comparing our results with a *Thermo FH 40 G*.

Measurement setup

Radioactivity

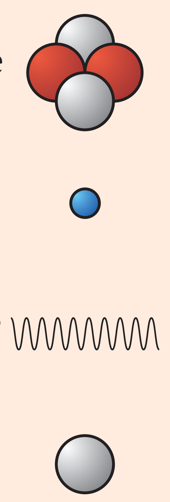
Definition
Radioactivity or *radioactive decay* is the process by which an atomic nucleus emits ionizing particles. The particles are characterized by their ability to liberate electrons from atoms and molecules - hence their name. Target material that is subject to such radiation can change its chemical and physical properties. In organic compounds, such as tissue, this leads to free radicals and biological damage.

Type	Particle	Mean travel distance in		Sources (R = nuclear fission in reactors, W = nuclear weapons)	Misc
		Air	Tissue		
α	Helium core	cm	μm	Plutonium (R, W), Uranium (R, W, reactor fuel), Americium (smoke detectors)	easily shielded, very dangerous when inhaled/ingested
β	electron	mm - m	μm - mm	Carbon-14 (radiocarbon dating), Strontium (R, W), Tritium (illumination)	causes skin damage
γ	electromagnetic radiation	m - km	cm	Caesium-137 (R)	causes deep tissue damage
n	neutron	**m - km**	**cm - m**	R	can turn target matter radioactive

(travel distances from *Physics for Radiation Protection*. J. E. Martin, 2000. ISBN 978-0471353737)

Ionizing radiation hazard sign

α particle
β particle
γ particle
neutron



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Conclusions

Preliminary measurements show reliable detection rates for α and β particles as well as γ radiation at high levels.

For **α radiation** we achieve a relative hit count of 1.10 x 10^{-2} ± 0.17 compared to the reference device, i.e. we count less hits but the error in doing so is low. The small value can be explained by the significantly smaller area of the sensor and to a lesser degree by the absorbing aluminum foil. Using this factor as a calibration value for the camera we can reliably measure the radioactivity of a given sample.
β particles can also be measured with high precision (error < 5%) but the relative hit rate depends on the material of the measurement sample - this indicates that the sensor's sensitivity varies with the particles' energy.
At high doses **γ radiation** can be measured as well. Their comparibly low detection rate can be explained by small spatial extent of the camera's sensor.
We could not detect **neutrons** even for strong sources and further modifications would be needed to do so, such as submersion in helium gas.