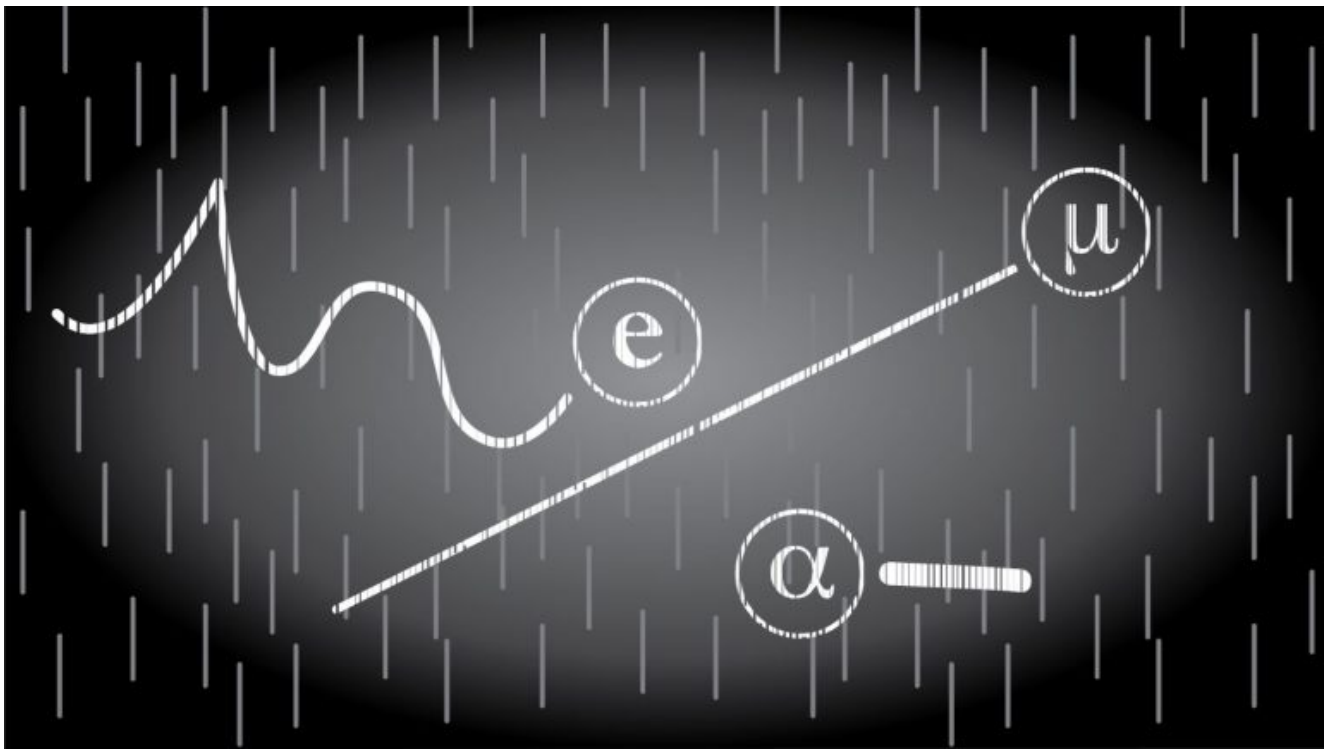
DIY Webcam Particle Detector

http://physicsopenlab.org/2016/05/18/diy-webcam-particle-detector/

18. Mai 2016



Introduction

The purpose of this document is to describe the use of a commercial webcam as a **particle detector**. We will show that, from an ordinary webcam, one can make a “low cost” detector can detect **beta particles, gamma radiation and cosmic rays**. The device can be used to make interesting experiments on radioactivity and make qualitative measurements of radioactive sources.

Radioactivity

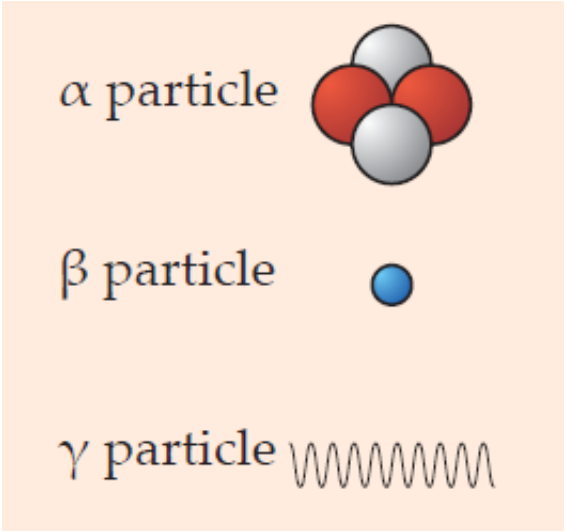
Radioactivity is the phenomenon whereby some nuclei, not stable, are

transformed into other emitting particles. Radioactivity was not invented by man, but on the contrary, man is exposed to radioactivity from the moment of its appearance on Earth. Radioactivity is as old as the universe and is present everywhere : in the Stars , the Earth and in our own bodies.

The isotopes occurring in nature are most stable. However, some natural isotopes, and almost all artificial isotopes, have unstable nuclei, due to an excess of protons and/or neutrons. Such instability causes the spontaneous transformation into other isotopes, and this transformation is accompanied by the emission of particles. These isotopes are called radioactive isotopes, or radioisotopes, or radionuclides.

The transformation of a radioactive atom leads to the production of another atom, which can also be radioactive or stable. It is called radioactive decay or disintegration. The average time it takes to wait for such a change could be extremely short or extremely long. It is said “average life” of the radioisotope, and can vary from fractions of a second to billions of years (for example, potassium-40 has an average life of 1.8 billion years). Another characteristic time of a radioisotope is the “half- time”, ie the time required for half of the radioactive atoms initially present undergoes a spontaneous transformation.

There are three different types of radioactive decays , which differ from the type of particle emitted as a result of the decay : **Alpha particles, Beta particles and Gamma radiation**.



α Radioactivity

The **alpha particles**, alpha rays are a form of highly ionizing corpuscular radiation and with a low penetration due to the high cross section. Consisting of two protons and two neutrons bound together by the strong force, it is therefore 4He nuclei. From a chemical point of view they may also be identified by the symbol 4He++. The beta decay is mediated by the weak force, while the alpha decay is mediated by the **strong force**.

Alpha particles are typically emitted from radioactive nuclides of heavy elements, for example the isotopes of uranium, thorium, radium, etc .., In a process called alpha decay. Sometimes this decay is leaving the nuclei in an excited state, and consequently the excess energy can be removed with the emission of gamma rays.

Alpha rays, because of their electrical charge, strongly interact with matter and therefore are easily absorbed by materials and can travel for only few centimeters in the air.

β Radioactivity

Beta radiation is a form of ionizing radiation emitted by many radioactive

nuclei types. This radiation is constituted by **beta particles** (β), which are high energy **electrons** or **positrons**, expelled by an atomic nuclei in a process known as **Beta Decay**. There are two types of beta decay, β− and β+, which emit an electron or a positron.

In the β− decay, one neutron is being converted in a proton, an electron and an electronic antineutrino (antiparticle of neutrino):

$$\mathrm{n} \rightarrow \mathrm{p} + \mathrm{e}^{-} + \bar{\nu}_e$$

In the β+ decay (in protons rich nuclei), one proton interacts with an electronic antineutrino to give a neutron and a positron (the direct decay of a proton in a positron has not been observed yet):

$$\mathrm{p} + \bar{\nu}_e \rightarrow \mathrm{n} + \mathrm{e}^{+}$$

Due to the presence of the neutrino, the atom and the beta particle do not normally recoil in opposite directions. The beta decay is mediated by the weak nuclear force. The interaction of beta particles with matter generally reach a length ten times, and ionizing power equal to one tenth compared to the interaction of alpha particles. They are completely blocked in a few millimeters of aluminum.

Y Radioactivity

In nuclear physics, **gamma rays** (often denoted by the corresponding lower case Greek letter γ) are a form of electromagnetic radiation at high energy, produced by decay or subatomic processes. The gamma rays are the most penetrating radiation produced by forms of decay, namely alpha decay and

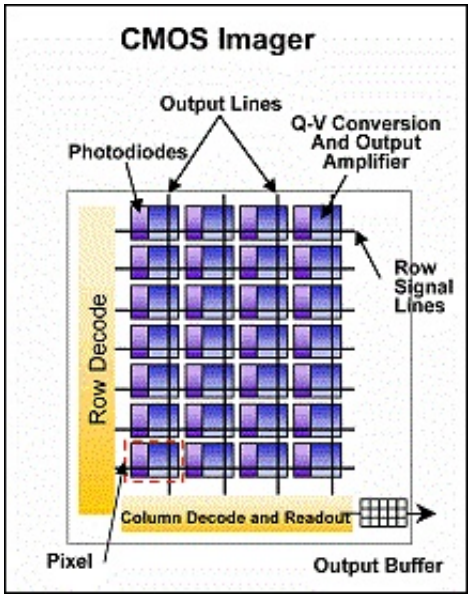
beta decay, because of the lower tendency to interact with the material.

Gamma rays are distinguished from X rays by their origin: gamma are produced by nuclear or other subatomic transitions, while X are produced by energy transitions due to fast-moving electrons in their quantized energy levels. Since it is possible for some electronic transitions exceed the energies of some nuclear transitions, high energetic x-rays overlap weaker gamma rays.

Webcam

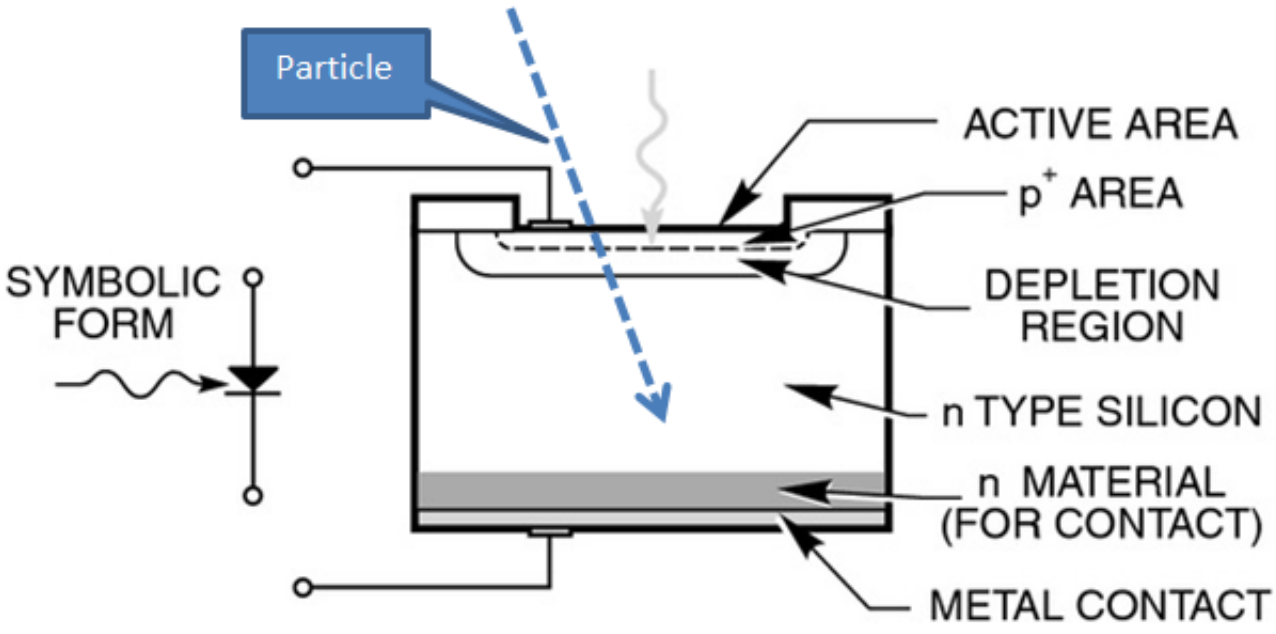
We used the webcam Logitech C270, readily available at any computer store or online (eBay, Amazon) for about 20 Euros. In order to use it as a particle detectors, the webcam should be modified. With attention you can make the changes in a reversible manner so as to be able to restore the original functionality.

Original camera



Inside the webcam is present the CMOS sensor that is the light-sensitive element. The CMOS sensor is in practice constituted by a matrix of pixels. Each pixel includes a photodiode and a conversion circuit / amplifier that converts the charge originated in the photodiode into a voltage that is read, pixel by pixel, and subsequently digitized into a numerical value **ranging from 0 to 255**. To select the color a tiny color filter (red, green and blue) is positioned above each pixel, resulting in a “mosaic” of colored pixels, then the image is processed in a timely manner (interpolation) to reconstruct the original image.

The active element, sensitive to particles, is the photodiode, shown schematically in the image below.



The ionizing particle enters into the sensitive area from the “top window” and produces in its passage several hundred electron / hole pairs which are collected by the cathode / anode of the diode and produce the signal that is subsequently digitized.

We give some data from the literature on solid state sensors :

Silicon Bang Gap = 1,115 eV

Couple Production Energy e/h (300°K) = 3,62 eV

Electron ionization power = 80 e/µm

As you can see from the data shown above, an electron which runs 10 µm produces about 1000 charge carriers, and thus an easily detectable signal, also because the electronic detection is local on the chip.

Actually the CMOS sensor is not optimized for the detection of the particles and therefore the detection efficiency is rather low, especially due to the fact that the sensitive region which is the depletion layer of the junction is very thin.

The alpha particles are not detected because the sensor is protected by a layer of glass (or other transparent material) that completely blocks the alpha particles.

Beta particles are partially absorbed by the surface protection but a high percentage reach the sensitive part and is detected.

Cosmic rays, which are high-energy muons, are detected practically 100 %.

For the gamma radiation the sensitivity is rather low and appears to be greater at low energies, this is also due to the small thickness of the sensitive

region of the CMOS sensor.

CMOS Sensor Data

The CMOS sensor in the Logitech C270 webcam features the following data :

Sensor Resolution = 1280 x 960

Pixel Dimension = 2,8 µm x 2,8 µm

Sensor Dimension = 3,5 mm x 2,7 mm

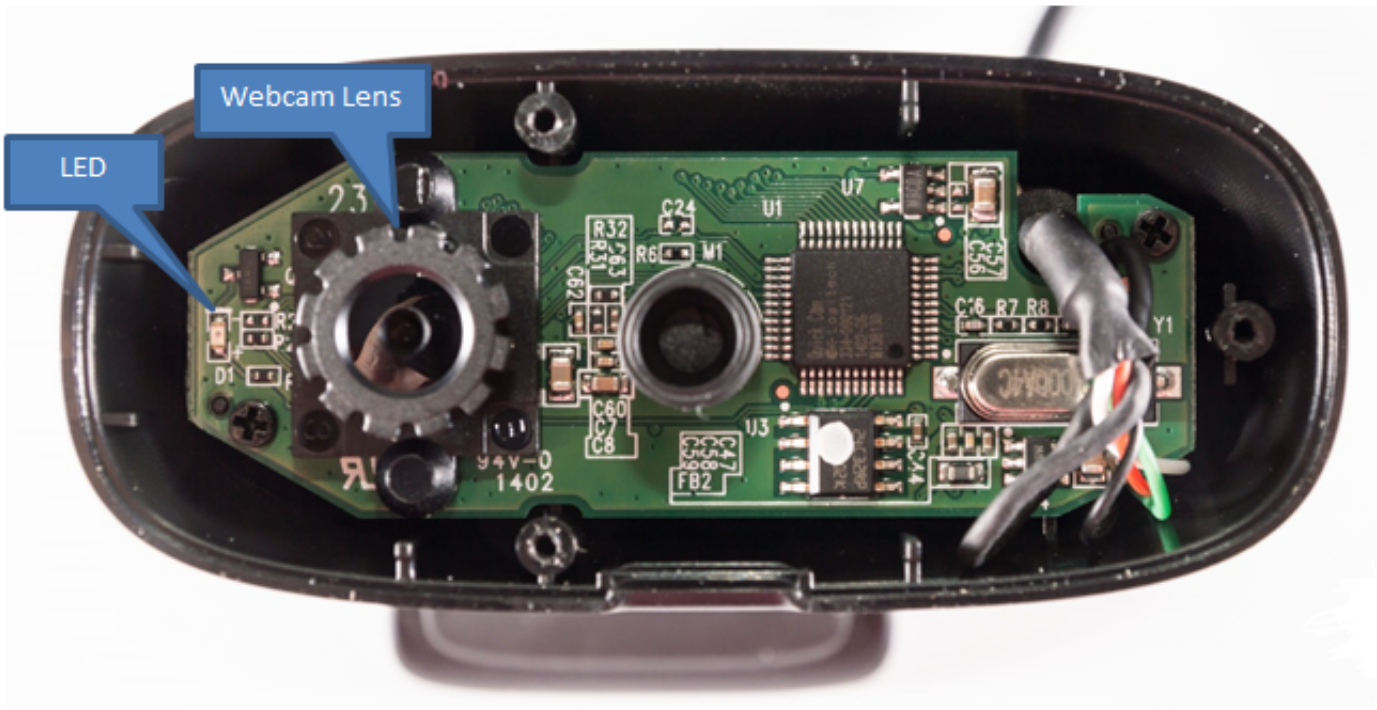
Sensor area = 9,45 mm^2

Image Resolution = 640 x 480

Image Pixel Dimension = 5,6 µm x 5,6 µm

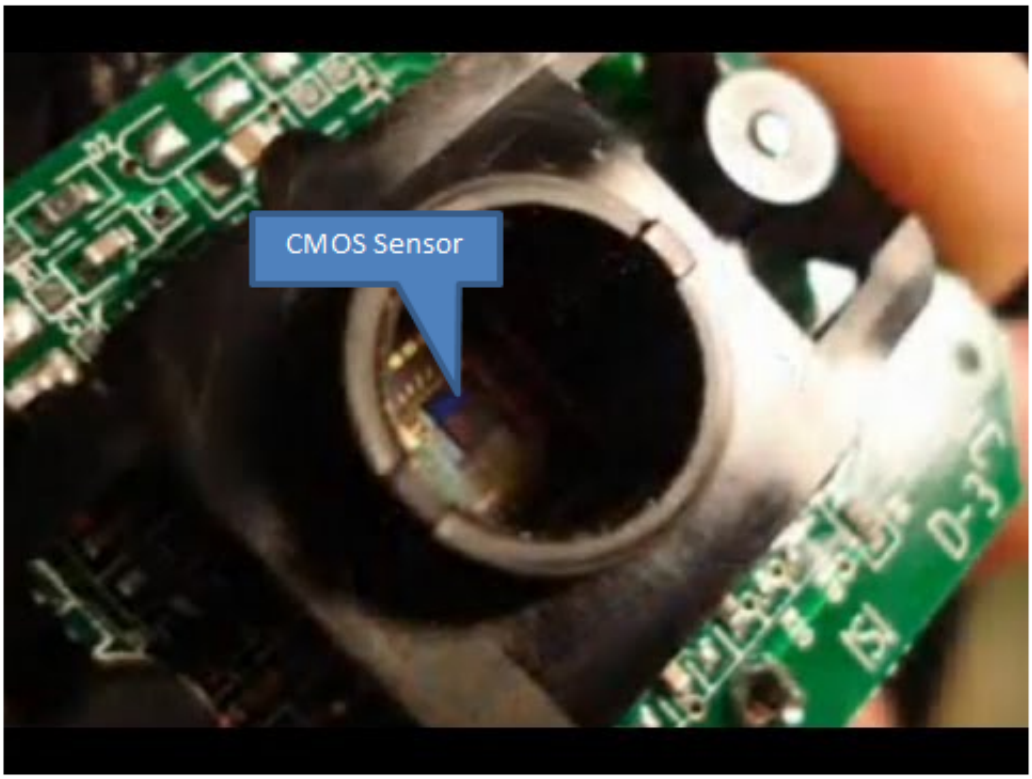
Webcam Hacking

Modifying the Webcam is very easy. First, the front cover must be removed by levering with a screwdriver, then dismantle the underlying base by removing the three small screws. The open Webcam is shown in the image below :



To prevent that the CMOS sensor is reached by LED light it is better to take it

off with wire cutters or with solder. It should also be taken off even the webcam lens, as seen in the image below.

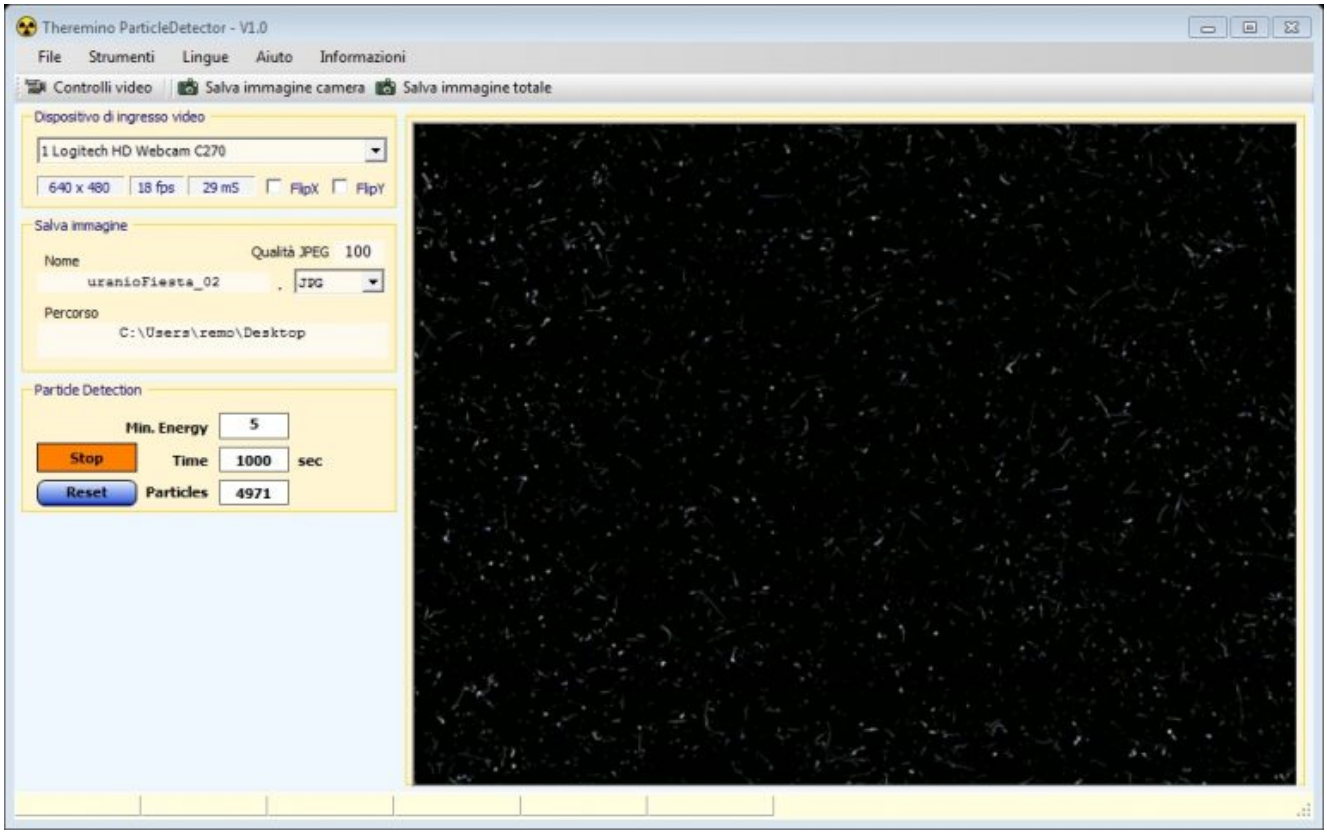


To avoid that the CMOS sensor is reached by the ambient light it is necessary to adequately shield it with an adhesive aluminum sheet, as shown in the figure below.

At the end the webcam can be mounted again using the covers previously removed.

Theremino Particle Detector

To capture the images recorded with the webcam it has been realized the **Theremino ParticleDetector** software. This software simply performs the **integration of the images** so as to achieve a sort of "**long exposure**". In this way the particle tracks are not erased at every acquisition cycle but accumulate frame by frame. In the picture below an example of a recording is shown.



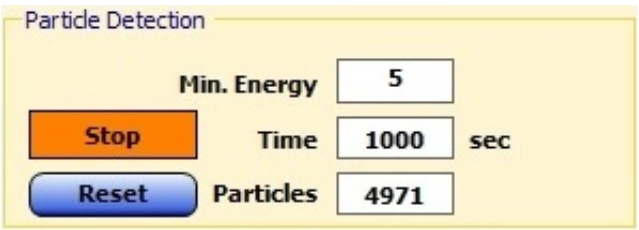
The application gives the possibility to set the **minimum energy (0 – 255**) in order not to count spurious events caused by the noise of CMOS sensor.

With the START / STOP control one can start and stop frame recording and events counting.

With the RESET control one can reset the integration time and the event counter.

During frame recording the events which are caused by a particle detection are counted and shown in the box "Particles", the total recording time is shown in the box "Time".

The ratio between these two values corresponds to the quantity "Counts per Seconds", that is CPS.



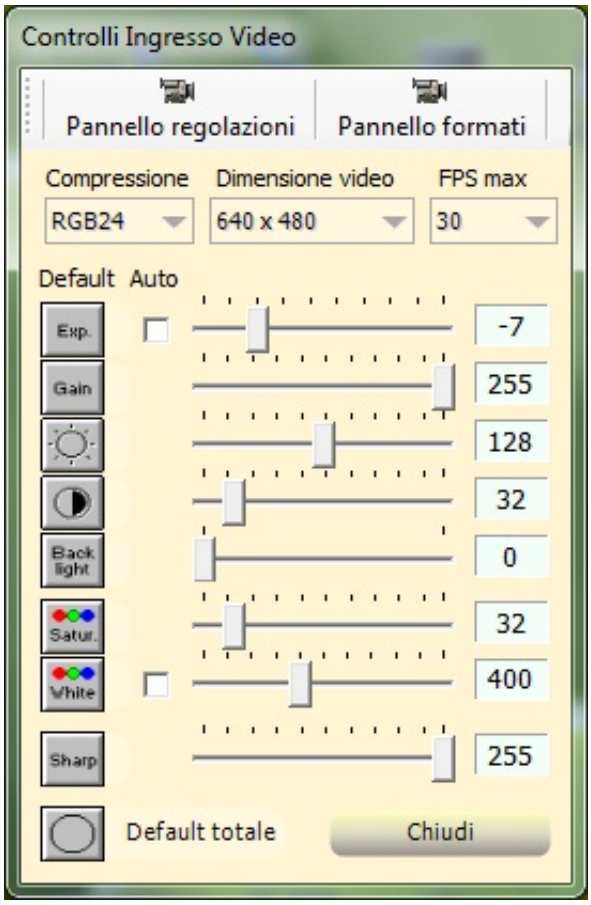
In order to obtain the best results it is advisable to set the Webcam with the parameters shown in the image aside. The following parameters are important :

Resolution = 640 x 480

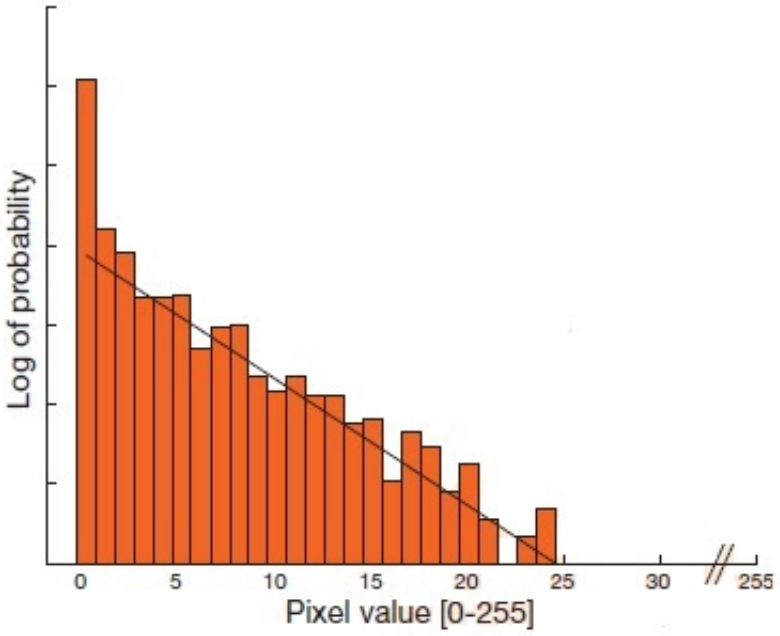
Exposure = -7 (corresponding to 1/10 s)

Gain = 255

Sharp = 255



It should be also adjusted the “minimum energy” parameter, used to exclude from the survey the events due to the noise of the CMOS sensor. From studies in the literature the distribution of noise has an exponential trend, as seen in the semilog graph presented below. By setting this threshold to values comprised between 5 and 20 most of the noise can be canceled.



Noise distribution

Zip with the application Theremino Particle Detector : Theremino_ParticleDetector

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