

BASIC EXPERTISE FOR SPATIAL RADIOMETRIC MEASUREMENTS

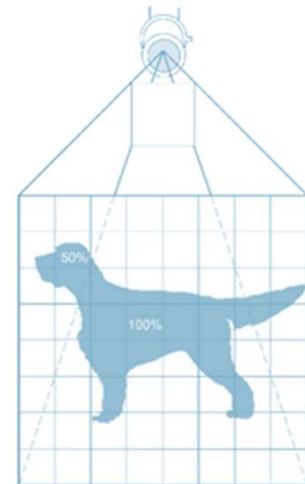
An IR camera optics is usually described by the same parameters as optics for the VIS spectrum, the main difference between the two is the material: For IR optics usually **Germanium, Silicon, Zinc Sulfide** or **Chalcogenide** is used, since these materials show good transmittance in the IR spectrum. The most common are Ge and Si, where Ge shows a better transmittance, but at the cost of higher price.

The two main parameters to describe the optic system is the **focal length** and the **f-number**. The focal length (f) determines in combination with the dimension of the focal plane area (FPA) the field of view (FOV) of the camera. The f-number (N) is the ratio of the focal length to the diameter of the entrance pupil (D). Since it is defined as $N=f/D$, the f-number gets smaller, the larger the entrance aperture gets. The smaller the f-number, the more radiation can be received by the IR sensitive chip, resulting in a better signal to noise ratio (SNR). Low f-numbers of course require a lens system with larger diameters, resulting in a higher price of the system. Furthermore, the f-number also has an influence on the dynamic range (temperature measurement interval) of the IR camera: The lower the f-number, the more radiation will be detected by the IR sensitive pixel at the same object temperature, resulting in a smaller object temperature measurement range. The object temperature measurement range can be expanded by optical filters, which cut off certain parts of the IR spectrum. This allows good SNRs for lower object temperatures, as well as increased measurement range.

The pixel pitch of the sensor and the field of view (FOV) of the optical system are the primary parameters, that define the spatial resolution of the measured object. In most cases, our standard optics are focused at infinity, meaning that objects will form a sharp image as long as their distance from the optical principal plane is sufficiently large.

However, if the projected image of an object, or more precisely, the image of its distinct features, becomes smaller than the pixel pitch, the corresponding pixel will register a mixed temperature value from both the object and the background.

For a visual explanation, refer to the following image:



There are two pixels, where the filling factor of the dog versus the background is shown. For the 100 % pixel the camera will detect the temperature of the specific part of the dog, but for the 50 % filled pixel, the camera will measure the super-position of the dogs head temperature and the background. In example: The dogs head temperature is 30 °C and the background is 20 °C. The measured temperature will be proportional by the fourth power of the temperature in Kelvin:

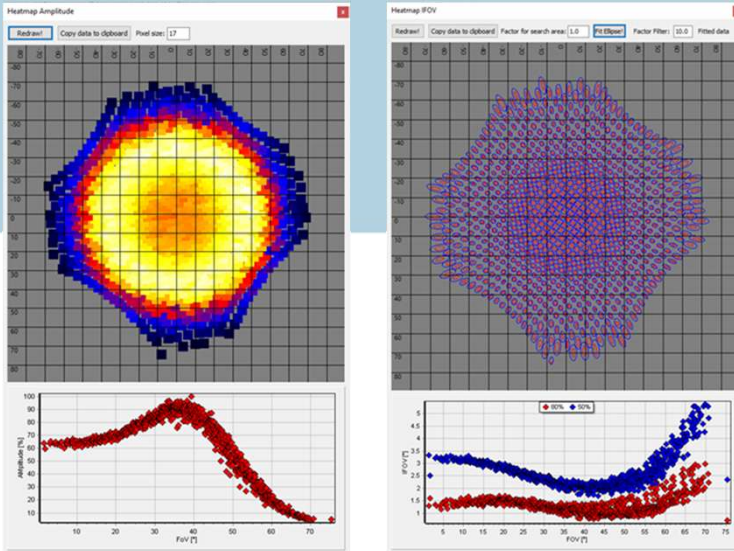
$$T_{meas} = \sqrt[4]{\frac{T_1^4 + T_2^4}{2}} = \sqrt[4]{\frac{((273.15 + 30)^4 + (273.15 + 20)^4)}{2}} = 298.28 K = 25.13 °C$$

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For small object temperature differences, like in the example, the measured temperature can be approximated by the T_{meas} formula above.

To determine, if an image is large enough for a filling factor of 100 %, also the laws of optics can be used: The image size can be easily calculated by $I=(O \cdot f) / d$, where O is the object size, f the focal length and d the distance of the object. The image size divided by the pixel pitch results in the number of pixels illuminated. In example: A human with a shoulder width of 50 cm is 1.5 meters distant from an HTPA32x32dL1.7. Therefore, $f=0.01m$, $O=0.5m$, $d=1.5m$ and $I=3,33E-3m$. With a pixel pitch of 90 μm , this result in 15 pixels illuminated.

For wide FOV optics, distortion becomes an important factor to consider. In the plot Heatmap Amplitude, the incident angle (X/Y axis) is shown against the amplitude (false color) of a 32x32dL1.7 sensor. The plot Heatmap IFOV illustrates the relative size of each pixel's measurement spot at 50 % and 80 % of its amplitude. For this system, a pixel located in the corner of the FPA covers an area approximately twice as large as that of a pixel in the center.

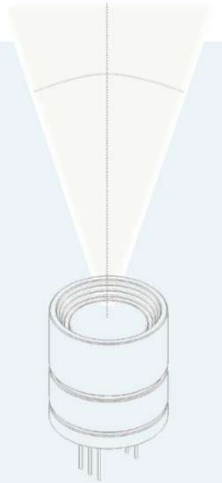


The ray law can coarsely determine the FOV of the camera:

$$FOV = 2 \cdot \arctan \left(\frac{P \cdot n}{2 \cdot f} \right)$$

P equals the pixel pitch, n the number of elements in the corresponding direction. This means the FOV can vary in x and y direction, if the number of elements is not equal in both directions.

In example: An 80x64 thermopile array has a pixel pitch of 90 μm . Combined with a 17 mm focal length optics the FOV will result in 24 ° x 20 °.



$$FOV = 2 \cdot \arctan \left(\frac{90e - 6 \cdot 80}{2 \cdot 0.017} \right) = 23.9^\circ$$

Note, that this formula does not work well for wide FOV optics, since the aberrations and distortions of the system cannot be considered.