Thermal technology glossary

1. AGC

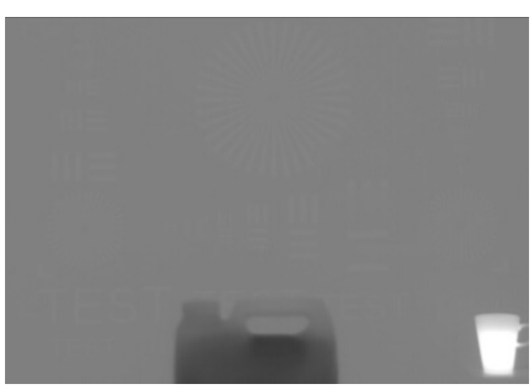
Automatic gain control (AGC) is a controlling algorithm that automatically adjusts the gain and offset, resulting into a visually pleasing and stable image. The incoming signal level for a visual camera can change rapidly, for example when the sun disappears behind a cloud. For a thermal camera, the corresponding rapid change could be something cold or hot entering the scene, the latter being a truck engine. For a thermal camera, the corresponding rapid change could be something hot entering the scene, such as a truck engine. By deploying different AGC techniques, both rapid and slow scene changes can be controlled so that the resulting image is as optimized as possible regarding brightness, contrast and other image-quality properties.

Snow

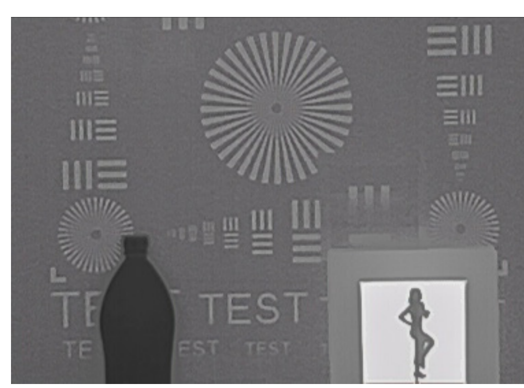
Heat from a running truck

AGC (Automatic gain control) also controls whether the output mapping from the sensor's 14-bit signal level to the 8-bit image is done linearly or by using a histogram-equalization curve. Histogram equalization redistributes the incoming signal levels, resulting in better image contrast. For example, in a scene with a big flat background and one small but very warm object, a linear curve would waste signal levels that are between the object and the background. The histogram equalization ensures that the signal levels are only spent on the background and the objects (and not on levels in between).

In Axis' thermal cameras, the default mode is a dynamic histogram equalization that varies the amount of equalization done depending on the incoming signal. In low-signal scenes, the resulting curve is almost linear, while in high-contrast scenes a lot of equalization is done. This means that the camera benefits from equalization in scenes wherever possible, and when there is only noise to enhance no equalization is done.



Linear



Equalization

2. Detection range

One of thermal cameras' primary tasks is to detect intruders at long distances. To specify a cameras' detection range the distance at which the camera can detect an object in perfect conditions Axis uses the Johnson's criteria.

Detection range according to Johnson's criteria

The resolution required to detect an object is stated in pixels and determined by means of Johnson's criteria. John Johnson, a U.S. military scientist, developed this method for predicting the performance of sensor systems during the 1950s. An object can be a person typically defined with a critical width of 0.75 m (2.46 ft), or a vehicle typically defined with a critical length of 2.3 m (7.55 ft). Johnson measured the ability of observers to identify scale model targets under various conditions, and came up with criteria for the minimum required resolution. These criteria provide a 50% probability of an observer distinguishing an object at the specified level. For a thermal sensor, the temperature difference between the object and its background needs to be at least 2 °C (3.6 °F), according to Johnson's criteria. The levels of Johnson's criteria used for Axis thermal network cameras are as follows:

> At least 1.5 pixels are needed for detection (when the observer can see that an object is present).

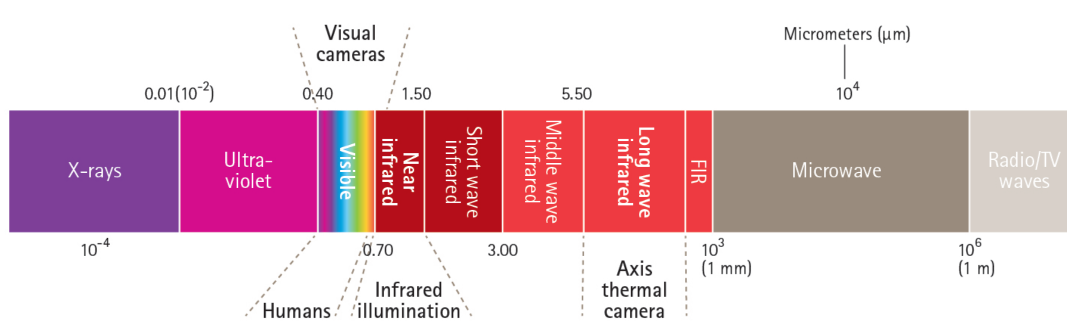
> At least 6 pixels are needed for recognition (when the observer can distinguish the object, for example, a person in front of a fence).

> At least 12 pixels are needed for identification (when the observer can distinguish an object and object characteristics, for example, a person holding a crowbar in his hand).

Johnson's criteria were developed under the assumption that visible information is processed by a human observer. If information is instead processed by an application algorithm, there will be specific requirements about the number of pixels needed on the target for reliable operation. All video analytics software algorithms need to work with a certain number of pixels, but the exact number of pixels may vary. Even if a human observer is able to detect the object, the application algorithm often needs a larger number of pixels at a given detection range to work properly.

3. Electromagnetic spectrum

Outside the visible range of light, we find infrared (IR) and ultraviolet (UV) light, which cannot be detected by the human eye. Visual camera sensors can detect some near-infrared (NIR) light, from 700 nanometers up to about 1,000 nanometers. If such light is not filtered out, it can distort image color. Therefore, a visual camera is equipped with a filter an optical piece of glass placed between the lens and the image sensor. This IR blocking is commonly called an IR-cut filter; it filters out near-IR light and delivers the same color interpretations that the human eye produces.



The IR-cut filter can be removed to extend a visual camera's ability, in order to produce quality images in low-light or dark situations. This allows a camera's image sensor to use the near-infrared light to deliver high-quality, black-and-white images. Cameras with the ability to make use of near-infrared light are often marketed as day-and-night cameras or IR-sensitive cameras. This does not mean that such cameras produce heat-sensitive infrared images. Infrared images require true infrared cameras that are specialized at detecting long-wave infrared (LWIR) light (heat) that radiates from both living and non-living objects. In infrared images, warmer objects (such as people and animals) stand out from typically cooler backgrounds. True infrared cameras are called thermal cameras.

Like all cameras, a thermal or temperature alarm camera collects electromagnetic radiation, which is transformed into an image. But while a conventional camera works in the range of visible light (with wavelengths between approximately 400 and 700 nanometers/[0.4–0.7 µm]), a thermal camera is designed to detect radiation with longer wavelengths. Thermal cameras typically work in either the Mid-Wavelength IR (MWIR) domain (approximately 3-5 µm) or in the Long-Wavelength IR (LWIR) domain (approximately 8-14 µm).

The uncooled microbolometer sensors used at Axis (and almost all microbolometer sensors) work in the LWIR spectrum, typically defined as between 8-14 µm. This is also the wavelength region where living objects (such as humans) have their peak on their Planck curve, which is one reason thermal cameras are so good at detecting humans.

4. Emissivity

All objects with a temperature above absolute zero (0 Kelvin [0 K or 273 °C or 459 °F]) emit infrared radiation. Even cold objects, such as ice, emit infrared radiation as long as their temperature is above -273 °C. The hotter an object is, the more thermal radiation it will emit. The greater the temperature difference between an object and its surroundings, the clearer the thermal images will be. However, the contrast of a thermal image doesn't only depend on the temperature; it also depends on the emissivity of the object.

The emissivity (e) of a material is a measure of its ability to absorb and emit radiant thermal energy. The emissivity is highly dependent on material properties, such as thermal conductivity (a measure of how well a material conducts heat). All radiation absorbed by a surface must eventually be emitted from that surface. All materials have an emissivity between 0 and 1. A so-called 'black body' absorbs all incident radiation and has an e=1, whereas a more reflective material has a lower e. Most materials such as wood, concrete, stone, human skin and vegetation have high emissivity (0.9 or higher) in the LWIR region. By contrast, most metals have a low emissivity (0.6 or lower) depending on their surface finish; the shinier the surface, the lower the emissivity.

Thermal radiation that is not absorbed by a material will be reflected. The higher the reflected energy, the higher the risk of misinterpreted measurement results. To avoid erroneous readings, it's important to select the camera's measurement angle so that reflections are minimized. If a material generally behaves like a mirror in the visual spectrum, it usually behaves like a mirror in the LWIR region as well. Such a material may be difficult to monitor, as the temperature reading may be influenced by other objects reflected in the monitored object. In general, Axis temperature alarm cameras work best with objects having a high emissivity (above 0.9), but objects with a lower emissivity (above 0.5) may be considered, if the measurement setup is carefully chosen.

To be considered false alarms can occur if, e.g. an alarm zone is defined around an entrance or glass door and a passing person is reflected in it. This reflection is enough to trigger the alarm. Similar case may occur with reflections in water or from puddles.

5. Exposure zone

To optimize a thermal camera's detection performance, it's important to set the exposure zone setting correctly, depending on the scene. It's not advantageous to calculate the histogram on the whole scene if the whole scene isn't interesting for the application. This will risk color levels being distributed on objects that aren't interesting. To solve this, the **exposure zone** setting must be set to the area of interest. The exposure zone means that the camera only optimizes the image for the defined region of interest and ignores other parts of the image, even if that means that they will completely disappear. This is extremely important and can greatly affect the camera's detection performance, even if the image as a whole looks good.

6. Lenses

A lens (or lens assembly) performs several functions. They include:

> Defining the field of view both how much of a scene and the level of detail to be captured.
> Controlling the amount of light passing through to the image sensor, so that an image is correctly exposed.

Focusing is done by adjusting either elements within the lens assembly or the distance between the lens assembly and the image sensor.

Athermalized lenses
There are several material properties of a camera system which are affected by the environmental thermal conditions. Due to these effects, optical systems will change their focus when the temperature changes. More precisely, the optical system can defocus when the temperature changes. As security cameras are usually deployed in environments with large temperature fluctuations, it's important that the optical system is not sensitive to the environment's thermal changes. This is especially critical in the infrared wavelength region. Passive athermalized optical system design is therefore a necessity for thermal camera security applications. Matching lens material with optical housing material is one example of passive athermalized lens design. Depending on the complexity of the optical system, there are of course many passive athermalization optical-system designs.

7. Microbolometer

While there are several types of microbolometers, two main types of uncooled microbolometers are VOx and a-Si. Using one or the other doesn't affect the thermal imaging. Each microbolometer constitutes a pixel.

8. NETD

Noise Equivalent Temperature Difference (NETD) is the most common measure of classifying the performance of a thermal sensor. NETD defines the noise threshold where objects with temperature difference below that value will disappear in the noise, and objects with differences above that value will be visible. The smaller the NETD, the better.

For example, if a sensor has a NETD of 50 mK, it means that a difference in temperatures below 50 mK will disappear in the sensors noise and cannot be seen.

However, NETD has two big drawbacks. First, there are a couple of different ways to calculate NETD that don't always yield the same result; NETD can also be calculated in different ambient temperatures and/or with different F-numbers, which yields different results. A second drawback is that specify NETD-values may not include spatial noise. This means that the NETD can be low even though the image is quite noisy.

These factors are important to remember when NETD from different sensors are compared. It's the most common value used to compare sensors, but it doesn't tell the whole story. It's also important to remember that while NETD is mainly a method to compare sensors, it's often used to compare cameras. This is even more difficult since so many other factors can affect the actual performance of the camera. For example, NETD does not take into consideration how well a camera is in focus; a camera out-of-focus can still get a good NETD-value.

In conclusion, NETD is a signal-to-noise measurement for thermal sensors. The smaller the better, but it's important to remember that it can be difficult to compare only NETD when comparing camera performance.

9. NUC

Uncooled microbolometer sensors usually have large non-uniformities due to fabrication variations. This means that two non-uniform pixels would represent temperature information differently. They are also very sensitive to changes in ambient conditions and when temperature changes noise is induced. This depicts itself as a spatial variation over the sensor for both offset and responsivity. In addition, there are also differences due to the optical imaging, e.g. different fields of view of the pixels. All these differences need to be corrected so the outgoing signal for a homogenous incoming signal is as uniform as possible. The common name for such a smoothing algorithm is **non-uniform correction** (NUC).

One way of correcting some non-uniformities, is to use a movable mechanical shutter, found between sensor and optics. Depending on the characteristics of the camera system, this shutter is conditionally moved to block the entire field of view, and an image is taken. The shutter image that is taken is then included in the NUC algorithm for removing this induced noise. The conditions for when a shutter image should be taken varies from algorithm to algorithm, and camera system to camera system, but it's often controlled by an internal temperature sensor and/or a timer. This image correction is always done at runtime, including freezing the image.

10. Pixel pitch

Pixel pitch is the distance between the centers of the pixel. Smaller pixel pitch means smaller sensor size for the same resolution, so that smaller optics can be used. This is especially important for thermal cameras, since the most common lens material (germanium) for thermal cameras is very expensive. Theoretically, larger pixels will receive more energy but in the end, the performance of the sensor depends a lot on the design of the pixel.

11. Thermal sensors

There are two main types of thermal sensors available on the market: cooled and uncooled.

a. Cooled
Cooled sensors are high-end systems often found in military applications. They are expensive, and are available in different subtypes. While the performance of cooled sensors is widely superior to the uncooled sensors, the price difference makes the uncooled sensor the only viable option for the regular, non-military surveillance market. Cooled sensors also have another downside: the cooler needs to be maintained with a certain interval to maintain the same performance over time. The increased total-cost-of-ownership, for thermal cameras supporting cooled sensors, typically makes them too expensive for non-military applications.

b. Uncooled
Uncooled sensors also come in different types but the most common type is the microbolometer thermal sensor. A microbolometer is basically a tiny resistor that changes resistance with temperature. By letting the incoming signal heat the microbolometer and then read out the resistance change compared to a "blind" microbolometer, a value for the incoming infrared radiation can be created. An image is created in an array of microbolometers pixels.

12. Thermography

Thermography (or thermal imaging) is a method where infrared radiation is converted to, and presented as, an image. Thermography is a very powerful tool for seeing heat differences in objects. If the thermal camera is calibrated, the thermal image can provide information on the object's surface temperature. When measuring the temperature of a specific surface, the camera is influenced by many other parameters such as the absorption, the emission, the reflection, the transmission and how the surrounding objects radiate the heat.

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