Allied Vision

APPLICATION NOTE

Temperature influence on image quality of SWIR cameras

V 1.1.0
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Introduction

During operation, power consumed and dissipated by the internal electronic components causes the interior and case of the camera to heat up. The InGaAs sensor is affected by temperature in two ways:

- An increase of the absolute sensor temperature has a negative impact on the image quality, and
- A difference in temperature may cause the sensitivity curve to drift or to become slightly narrower.

This application note describes the reason for the decrease in image quality and explains the technique for remedy implemented in Goldeye cameras.

Infrared spectrum

Within the electromagnetic spectrum, the infrared region is located between the red part of visible light and microwaves. It covers a very broad part of the spectrum, with wavelengths from 750 nm to 14,000 nm. Usually, the infrared radiation is subdivided into four regions: near infrared (NIR), short wave infrared (SWIR), medium wave infrared (MWIR) and long wave infrared (LWIR).

The SWIR range encompasses only the small part adjacent to visible light from 900 nm to 2700 nm. Infrared radiation in the NIR and SWIR range is reflected from objects in a similar way to visible light, hence it is also called “reflected IR”. However, it is not visible to the human eye. In contrast, the MWIR and LWIR range of infrared radiation is called “thermal IR” since it is not reflected but generated and radiated from warmer objects. Therefore, different sensor types are used for visible light, for the SWIR range and for the LWIR range, respectively.

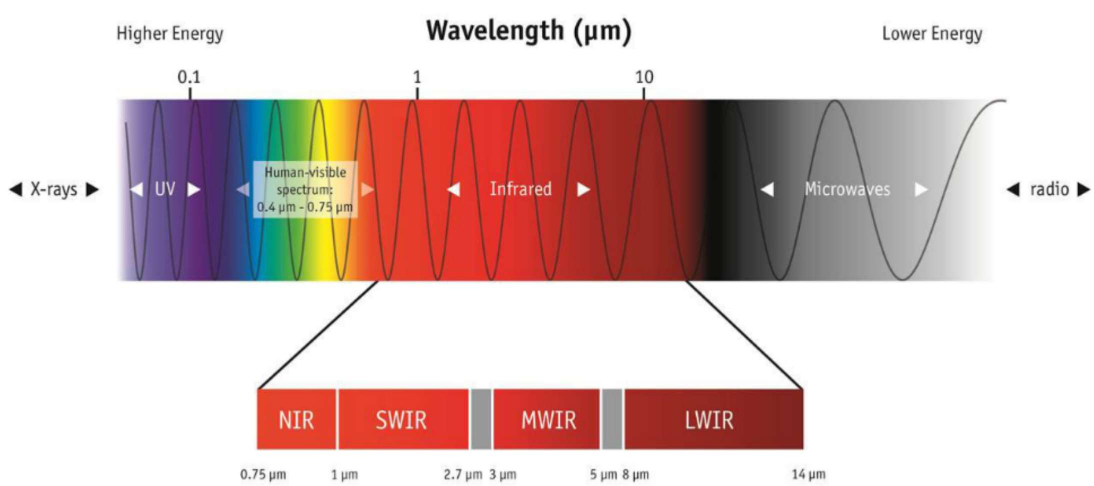

Figure 1: Visible and infrared range as part of the electromagnetic spectrum

Allied Vision SWIR cameras are sensitive in the range from 900 nm to 1700 nm. The SWIR cameras are equipped with InGaAs sensors that are made of Indium-Gallium-Arsenide based photo diodes and a CMOS readout circuit. The infrared sensors are quantum detectors. That means they detect the photons and convert them to electrons.

The InGaAs detector array is bonded to the readout circuit on a pixel-by-pixel basis. The bonding leads to more irregularities and defects within the sensors that need to be corrected.

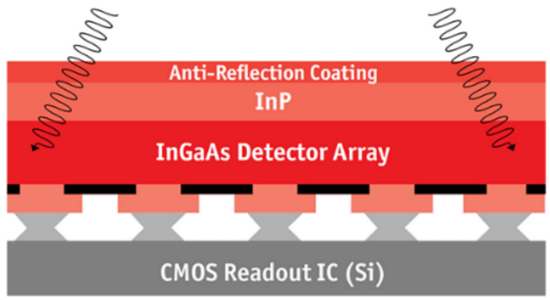

Figure 2: Simplified schematic of typical InGaAs sensor design

Dark current

One of the most important influences on image quality is dark current. Dark current is the relatively small voltage that flows through charge-coupled devices, even if no radiation is present and thus no photons are converted to electrons. It is to a large part due to thermal excitation of electrons in the InGaAs material. Dark current produces a signal even if it is completely dark.

In addition, the dark current generates additional offset and noise, especially at longer exposure times, which leads to a reduction in image contrast in the area of the useful signal.

Influence of the temperature influence on image quality

Dark current is strongly temperature dependent: the higher the temperature, the stronger the dark current. In most cases, it is due to the generation of electrons within the depletion region of the device.

If the sensor temperature increases, this means also an increase of the dark current of the FPA's photo diodes, thus decreasing the dynamic range of the camera. As a rule of thumb, a temperature increase of 9 Kelvin doubles the dark current.

The graph in Figure 3 shows, in counts per second, how the dark current increases strongly with increasing sensor temperature.

The absolute value of the dark current can vary considerably between various sensors. As an example, the graph in Figure 3 was created using measurement data from a single Goldeye G-033, using Gain 0.

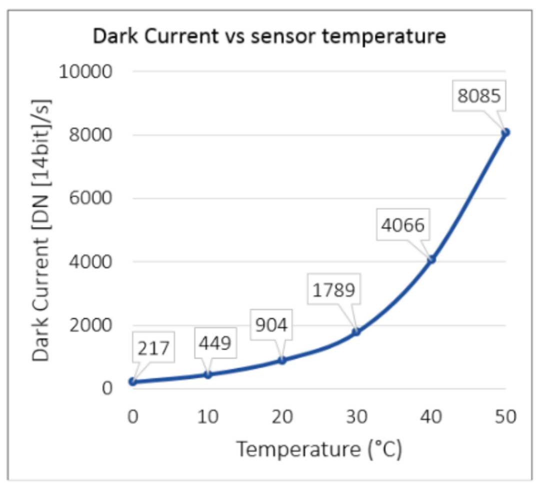

Figure 3: Dark current in counts in dependency of the sensor temperature.

Example

The following example shows how temperature affects the actual camera images.

The same scene was taken twice at an exposure time of 100 ms, using Gain 0. The first image was taken at an ambient temperature of 20 degrees Celsius, the second image was taken at 45 degrees Celsius.

The resulting images and their histograms are shown in Figure 4. The differences between both images are visible to the naked eye already. However, they become particularly noticeable when the histograms are compared closely.

On the lower end of the 20 degrees Celsius histogram, we see two peaks, and more pixels than on the same range in the 45 degrees Celsius histogram. The difference is obvious at the high end of the histograms, where the 45 degrees Celsius histogram shows many more pixels. There is even a peak at the far right end of the 45 degrees Celsius histogram that means there are saturated pixels in that image. In the 20 degrees Celsius image, there are no saturated pixels. Saturated pixels do not provide any information, therefore saturated pixels should always be avoided. To make the difference more visible, both histograms were overlaid with the same red lines.

Goldeye CL-033 TEC1:
20 °C sensor temperature

Goldeye CL-033 TECless:
45 °C sensor temperature

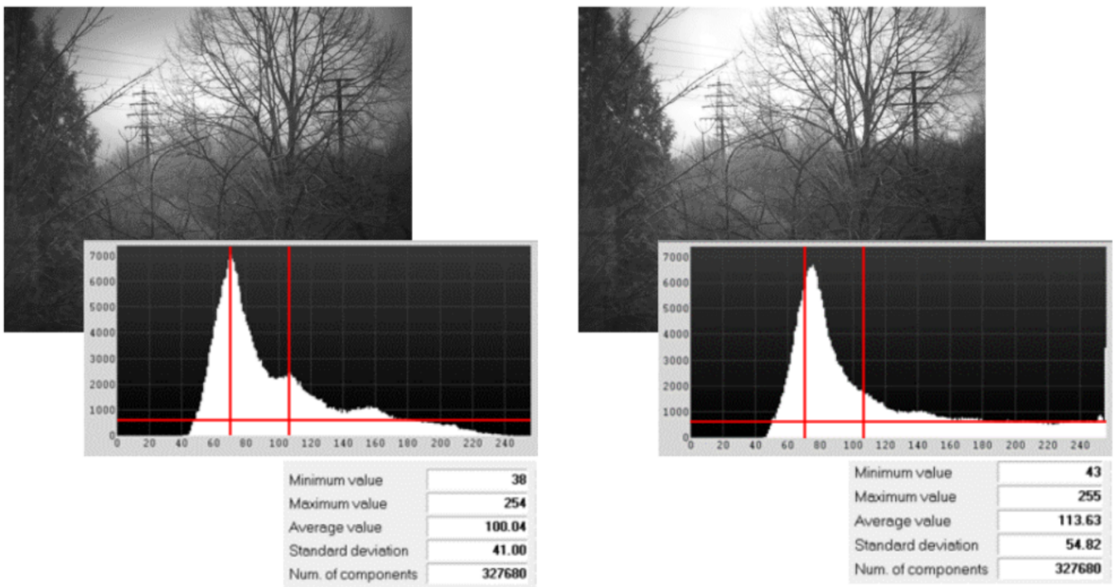

Figure 4: The same scene taken twice, including the corresponding histograms and image statistics.

A comparison of the image statistics shows that the minimum value of the 45 degrees Celsius image is clearly higher, meaning that the black level has increased. Similar to saturated pixels, the very dark part of the image below the black level does not provide any information. Also, the average value and the standard deviation of the pixels have increased.

That means that the image quality, or the black level in the noise, is strongly influenced by dark current, so temperature control is very important in many applications.

Spectral sensitivity drift

Temperature has a high influence on the spectral sensitivity of the SWIR cameras. Experience shows that a decrease in temperature by 40 Kelvin (from +25 to-15 degrees Celsius) causes a drift of the spectral sensitivity of about 25 nm towards lower wavelengths.

The spectral sensitivity of the three InGaAs sensors built into Goldeye cameras is rather flat throughout the main range from 1000 to 1600 nm, with steep slopes at both ends of the range (see Figure 5 on page 4).

This drift strongly affects the quantum efficiency (QE) in both upper and lower transition slope areas and is of great importance for applications operating close to the low or high end of the sensitivity curve.

The practical effect of the sensitivity drift is visible in Figure 6. The drift to the left changes the size of the QE for each wavelength of the sensitivity range.

It is clearly visible that the effect has its greatest influence in the area of the slopes at the upper and lower end of the range that are marked yellow.

Example

The task of plastic sorting is to identify and sort chips from shredded plastic containers and bottles. The old plastic is delivered in soiled and mixed bales. Nevertheless, the result of the sorting process must be absolute grade purity.

Chips of polyethylene terephthalate (PET) and polyvinyl chloride (PVC) are difficult to distinguish in visible light, but pure sorting results are essential for sorting these special polymers. Only a few parts per million PVC material within the PET material render the recycled material unusable.

PET and PVC materials are distinguished by their dominant absorption peaks in the SWIR range. These absorption peaks are at 1660 nm for PET and at 1716 nm for PVC. They are shown as bars in Figure 7.

If temperature change causes a sensitivity drift, as shown by the blue and red lines in Figure 7 for a temperature change of 60 K, this means in practical terms that the quantum efficiency will greatly change at any given wavelength.

Therefore, if sensitivity drift occurs, no longer is the grade purity necessarily guaranteed after sorting.

In order to achieve a constantly high-quality sorting result, a constant sensor temperature is therefore very important. Equally important is the absolute temperature level.

When sensitivity above 1650 nm is required, the sensor temperature should not be too low, which practically means below 20 °C. Even if the dark current and noise increase with an increase in temperature, the signal at the higher end of the spectrum might still be better and more usable.

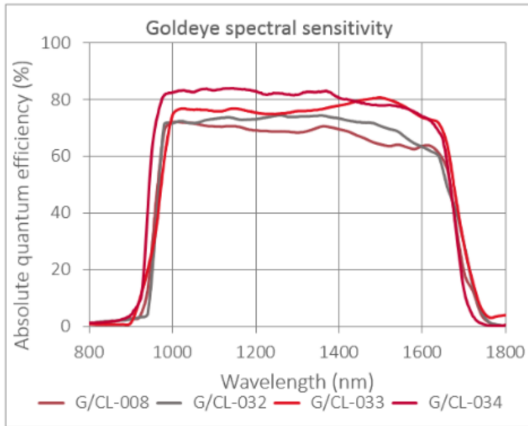

Figure 5: Goldeye spectral sensitivity

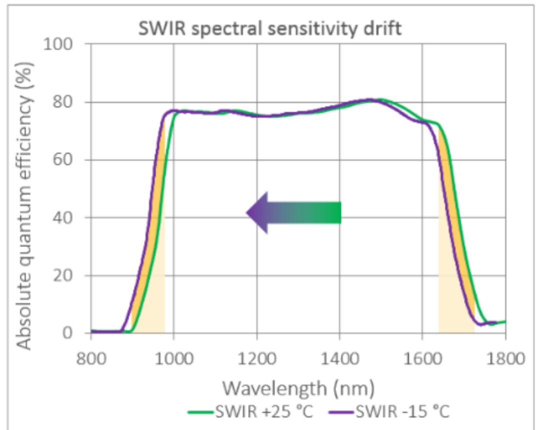

Figure 6: SWIR spectral sensitivity drift

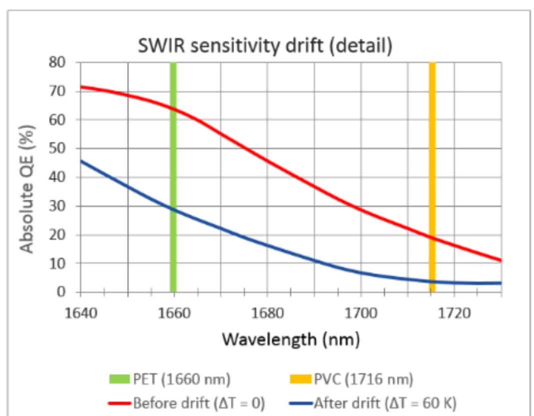

Figure 7: SWIR sensitivity drift (detail)

Conclusion: temperature control is crucial

The sensor temperature level influences the spectral sensitivity and the dark current. Dark current has a high impact on image quality (black level and noise). For applications where image quality is important and when operating at the low or high end of the sensitivity curve, temperature control is crucial.

To accurately monitor and control the temperature, all Goldeye cameras have three temperature sensors integrated:

- Inside the InGaAs sensor housing
- On the sensor board
- On the mainboard

Goldeye cameras provide advanced tools to correct and minimize the effects caused by temperature changes, for example, advanced background correction (BC).

To counterbalance the temperature difference between ambient and sensor temperature and to stabilize the sensor temperature, most of the Goldeye cameras are equipped with an active thermo-electric cooling device. Available cooling devices are:

- TEC1: single-stage thermo-electric sensor cooling (for example: Goldeye G/CL-033 TEC1)
- TEC2: dual-stage thermo-electric sensor cooling (for example: Goldeye G/CL-032 Cool TEC2)

To enable a stronger sensor cooling versus the housing temperature, Goldeye Cool models enclose the sensor in a nitrogen filled cooling chamber (for example: Goldeye G/CL-008 Cool TEC1). This protects the sensor from condensation and makes the camera suitable for environments where condensation is likely to occur, for example at high humidity and ambient temperatures.

Due to the stronger sensor cooling in Goldeye Cool cameras the power consumption is higher and more heat needs to be dissipated. Therefore, Goldeye Cool cameras are equipped with a fan to actively dissipate the heat that builds up internally. The rotation speed of the fan is controllable and can be switched of when needed, that is, to prevent any vibrations.

Another important side effect provided by the active sensor cooling is the reproducibility of measurements derived from the images captured. This is especially important for hyper-spectral and laser beam profiling applications.

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