APPLICATION NOTE

Image Quality versus Temperature on SWIR Cameras

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Introduction

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

- Increasing the absolute sensor temperature the image quality is decreased.
- Variations in temperature can cause the sensitivity curve to drift or to become slightly narrower.

This application note describes how image quality is decreased and it explains how Goldeye cameras compensate for this.

Infrared spectrum

In 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. Because infrared radiation in the NIR and SWIR range is reflected from objects in a similar way to visible light, 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 are called "thermal IR", since they are 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.

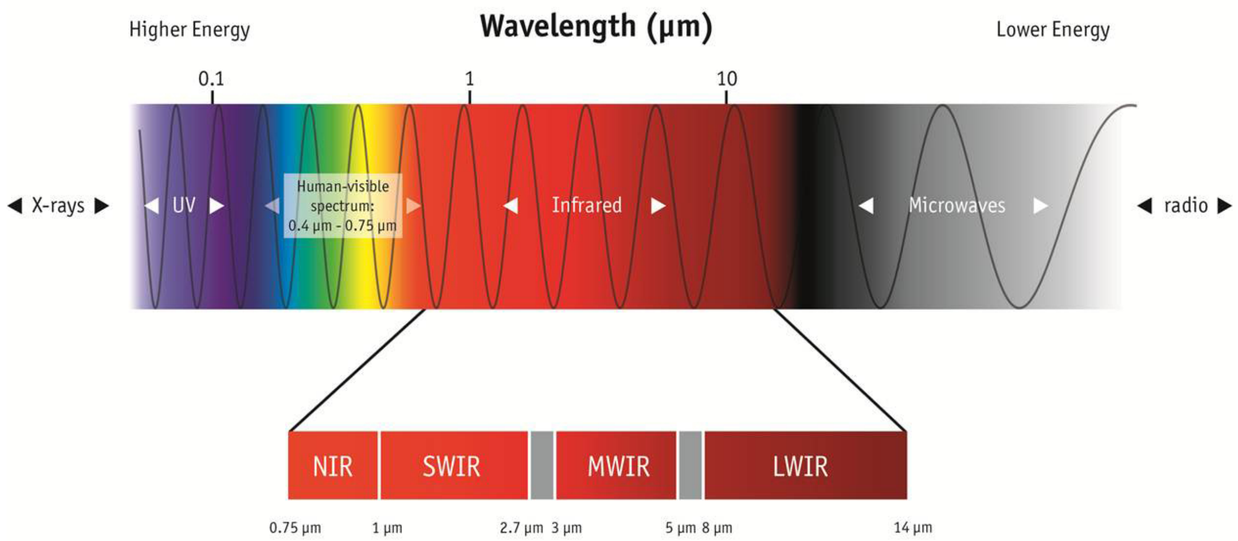

Figure 1: Visible and infrared range as part of the electromagnetic spectrum

InGaAs sensors

Goldeye SWIR cameras are sensitive in the range from 900 nm to 1700 nm. These cameras are equipped with InGaAs sensors that are made of Indium-Gallium-Arsenide (InGaAs) 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 sensor defects that must be corrected.

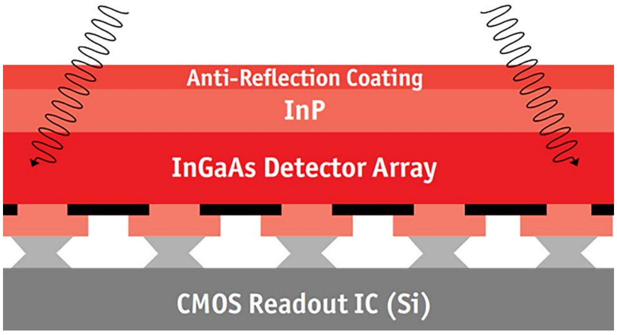

Figure 2: Simplified schematic of typical InGaAs sensor design

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 no photons are converted to electrons. It is mainly caused by thermal excitation of electrons in the InGaAs material. Dark current produces a signal even if the object scene is completely dark.

In addition, dark current generates additional offset and noise, especially at longer exposure times, reducing the image contrast for the useful signal range.

Temperature influence on image quality

Dark current strongly depends on temperature: The higher the temperature, the stronger the dark current. It is mostly generated by electrons in 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/CL-033 at Gain 0.

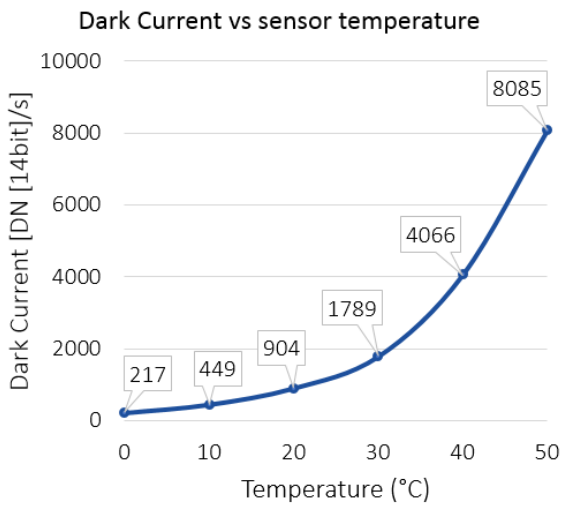

Figure 3: Dark current in counts in dependency of the sensor temperature

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 C°, the second image was taken at +45 C°.

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.

Histogram interpretation

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

Goldeye G/CL-033 **TEC1**
at +20 °C sensor temperature

Goldeye G/CL-033 **TECless**
at +45 °C sensor temperature

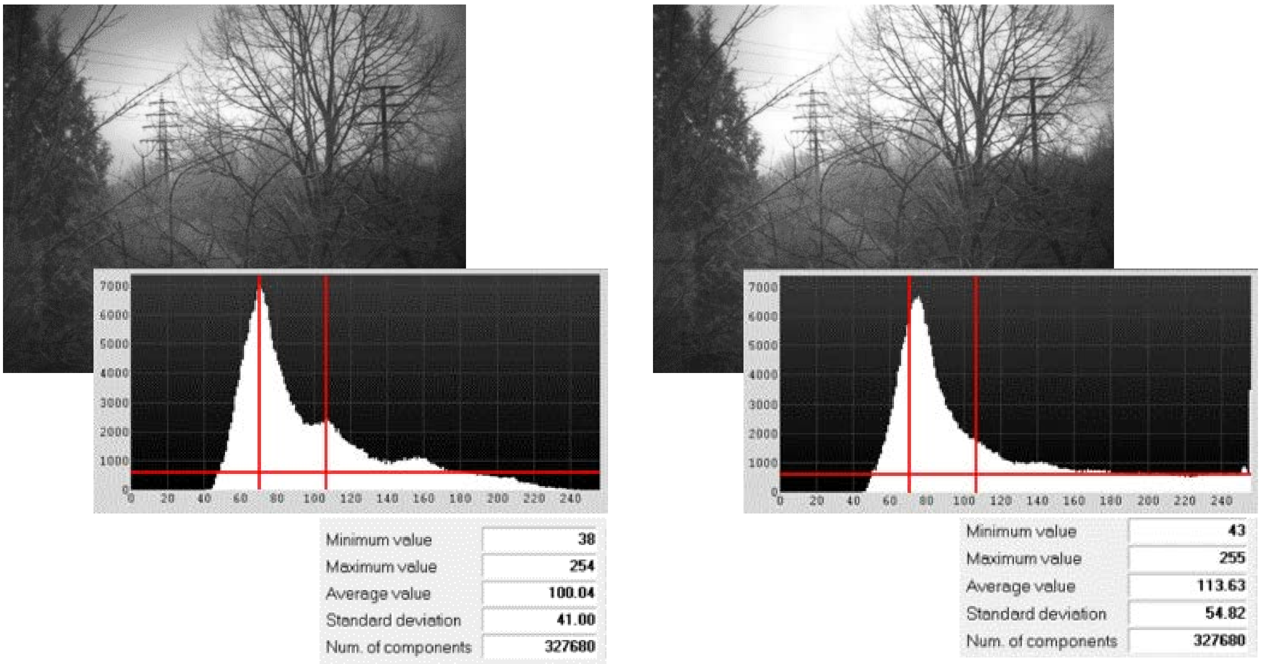

Figure 4: The same scene taken twice, including the corresponding histograms and image statistics

A comparison of the image statistics shows that the minimum value of the +45 C° 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.

This shows that dark current strongly influences the image quality and the black level in the noise. Therefore, temperature control is very important in many applications.

Spectral sensitivity drift

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

The spectral sensitivity of the 4 different InGaAs sensors in Goldeye cameras is rather flat throughout the main range from 1000 to 1600 nm, but with steep slopes at both ends of the range (see Figure).

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.

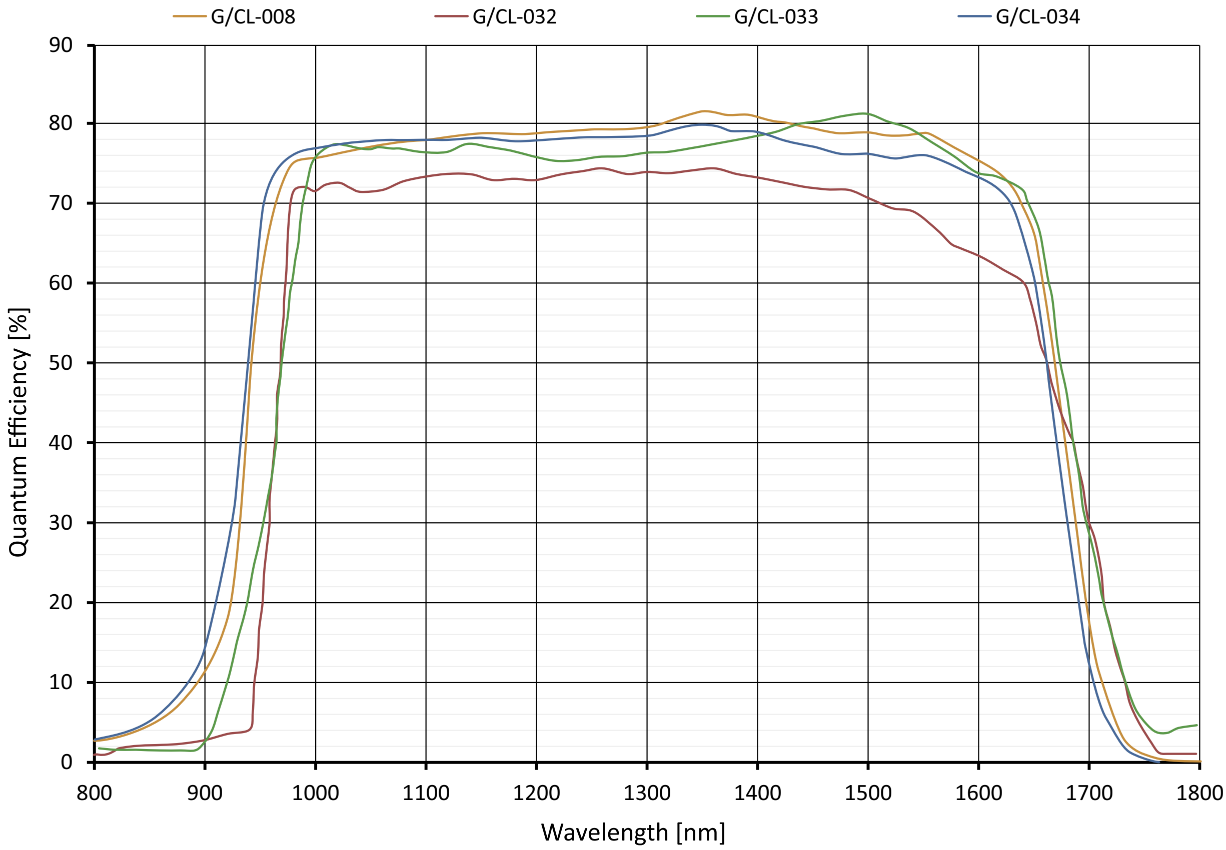

Figure 5: Spectral sensitivity for several Goldeye models

The practical effect of the sensitivity drift is visible in Figure on page 5. 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 of PVC material in the PET material render the recycled material unusable.

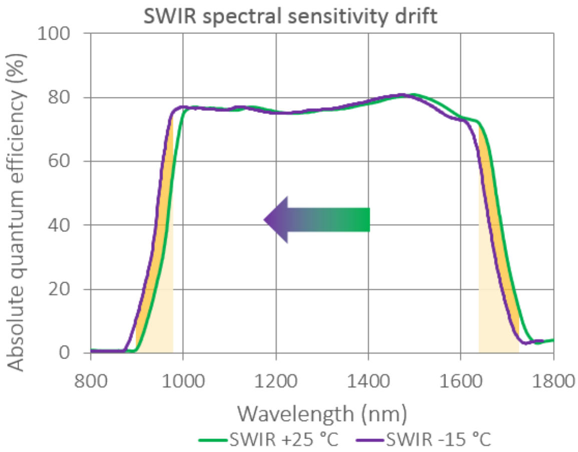

Figure 6: SWIR spectral sensitivity drift

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: Blue and red lines mark a temperature change of 60 K.

If temperature change causes a sensitivity drift, this means that the quantum efficiency greatly changes at any given wavelength.

Of course, the grade purity for proper sorting is not guaranteed when sensitivity drift occurs. In order to achieve a constantly high-quality sorting result, the sensor temperature must be constant.

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 may still be better and more usable.

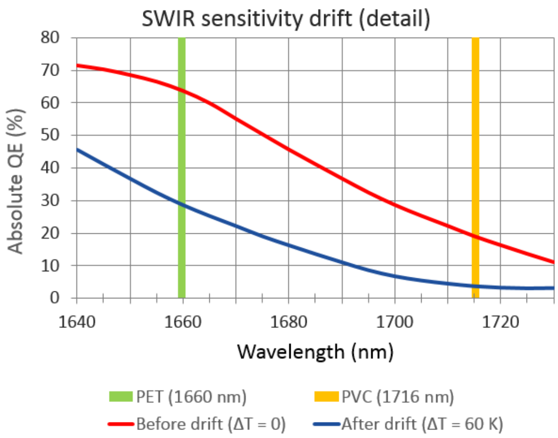

Figure 7: SWIR sensitivity drift (detail)

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). As a consequence, temperature control is crucial for applications that require high image quality and for applications that use the low or high end of the sensitivity curve.

To monitor and control the temperature accurately, all Goldeye cameras have 3 temperature sensors:

- 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).

TEC (thermo-electric cooling)

To counterbalance the temperature difference between ambient and sensor temperature and to stabilize the sensor temperature, most of the Goldeye cameras are equipped with active TEC (thermo-electric cooling) devices:

- TEC1: Single-stage thermo-electric sensor cooling, such as in Goldeye G/CL-033 TEC1
- TEC2: Dual-stage thermo-electric sensor cooling, such as in Goldeye G/CL-032 Cool TEC2.

For stronger sensor cooling against 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 high ambient temperatures.

Because of the stronger sensor cooling, Goldeye Cool cameras have a higher power consumption, resulting in more heat that must be dissipated. To compensate for this, 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 off, for example when vibrations are not allowed.

Moreover, measurements derived from captured images can be reproduced better with active sensor cooling. This is especially important for hyper-spectral and laser beam profiling applications.

Contact us

Website, email

General
www.alliedvision.com/en/contact
info@alliedvision.com

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Offices

Europe, Middle East, and Africa (Headquarters)
Allied Vision Technologies GmbH
Taschenweg 2a
07646 Stadtroda, Germany
T// +49 36428 677-0 (Reception)
T// +49 36428 677-230 (Sales)
F// +49 36428 677-28

North, Central, and South America, Canada
Allied Vision Technologies Canada Inc.
300 – 4621 Canada Way
Burnaby, BC V5G 4X8, Canada
T// +1 604 875 8855

USA
Allied Vision Technologies, Inc.
102 Pickering Way- Suite 502
Exton, PA 19341, USA
Toll-free// +1-877-USA-1394
T// +1 978 225 2030

Asia-Pacific
China
Allied Vision Technologies Shanghai Co Ltd.
B-510, Venture International Business Park
2679 Hechuan Road
Minhang District, Shanghai 201103
People's Republic of China
T// +86 21 64861133

Japan
Allied Vision Technologies
Yokohama Portside Bldg. 10F
8-1 Sakae-cho, Kanagawa-ku
Yokohama-shi, Kanagawa, 221-0052
T// +81 (0) 45 577 9527

Singapore
Allied Vision Technologies Asia Pte. Ltd
82 Playfair Rd, #07-01 D'Lithium
Singapore 368001
T// +65 6634 9027

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