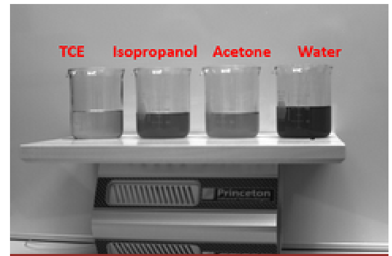
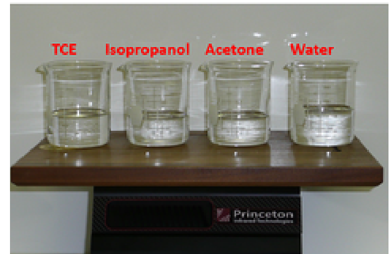
Princeton Infrared Technologies

WHY SIGNAL TO NOISE MATTERS IN SWIR IMAGING

BECAUSE YOUR LOW COST SWIR CAMERA IS NOT DETECTING YOUR SAMPLE



SWIR



VISIBLE

Why are some SWIR cameras not able to image or detect what their users want to see? Often users blame the SWIR band, but the real problem is practitioners are using the wrong tool for the job (i.e. you cannot pull your camper with a moped). This note will provide a background and explanation on why sometimes a high sensitivity camera is needed to get the job done versus using a low cost SWIR camera.

Background

For a long time, Short Wave Infrared (SWIR) imagers were not commonly used for inspection. It was difficult to conceive of using a SWIR camera to inspect something with non-visible light that one cannot see with one's own eyes.

SWIR is often defined as a band of light from 900-1700nm because that is the standard detection range for Indium Gallium Arsenide (InGaAs) detectors, but technically the SWIR band is from 1100-2600nm. With InGaAs detectors, the short wavelengths turn on at 900nm. Any light shorter than 900nm is absorbed by Indium Phosphide (InP), the substrate material that the InGaAs detector material is grown on. InGaAs material turns off at 1700nm because of the chemical structure of $In_{53}Ga_{47}As$ (the exact structure for InGaAs). Newer SWIR cameras, like Princeton Infrared Technologies' (PIRT) imagers, have the InP substrate removed to allow detection to start at 400nm. There are also extended InGaAs detectors that image all the way up to 2600nm, but these have much higher noise, require cooling and are significantly more expensive.

Signal to Noise Ratio (SNR)

In detection, there are two key elements, signal and noise. A high SNR is needed for an imager to work well with computer algorithms to conduct detection and differentiation. The signal to a detector is determined by the quantum efficiency (QE), which is how efficiently the detector material turns a photon into an electron/hole pair or measurable signal. InGaAs has very high QE, greater than 80% between 950-1650nm, which is why it is an ideal material for imaging in the SWIR. A competing technology known as Colloidal Quantum Dots (CQDs) has less than a 10% signal across most of the SWIR wavelength range. This is a factor of 8x difference in signal output.

The other key factor in image detection is noise. Noise has many components, but two are key in SWIR imaging devices. There is read noise and shot noise from the dark current. Dark current is an extraneous signal that is formed in the imager material even in the dark. During an integration time (exposure time) when the imager is collecting a signal, the imager is also collecting shot noise from the dark current that adds to the overall noise of the signal measurement being collected. The longer the exposure time the more shot noise that is created. The key is to have a detector material with low dark current to minimize this “bad” signal thus to minimize the noise. The read noise is the noise that occurs every time an imager takes a frame of data, no matter how long the integration time. Whether a long or a very short integration time, the read noise is the same. These two noises when added together in quadrature make up the total noise.

In dealing with a low signal, it is important to have a camera with low dark current and low read noise otherwise the user may not “see” what needs to be detected because the real signal will be lost in the noise. This is quite common. An example that we are all familiar with is using a camera phone in a poorly lighted room. The object being imaged is dark because not enough photons (signal) are getting back to the camera from the object to see it above the noise, so it appears black. Generally, camera phones extend the exposure time to collect more signal, leading to a very low frame rate. However, this can cause the image to be blurry because the camera cannot be held still enough. Figure 1 shows nine different images that demonstrate the differences when the signal is low to high versus the noise in a more qualitative format. More data and better pictures are available when the SNR is higher. This is critical in machine vision applications.

Figure 1. Simulated SNR effects on a single image with SNR of (top row) 0.001, .01. 0.1, (middle row) 1.0, 10 and 100, (bottom row) 1,000, 10,0000 and 100,0000. One can see how the SNR drastically effects the amount of information that could be gathered.[1]

PIRT compared its 1280MVCam to two common cameras on the market. One was a 5μm pitch InGaAs camera and the other a 15μm pitch CQD camera. We looked at two conditions, a low flux level (a small amount of light impinging on the image sensor) and then at a higher flux level (or a large amount of light). Flux is defined as the amount of power per area (mW/m^2), and power is measured as watts/second. The wavelength of light dictates the amount of energy in each photon. We used 1400nm as the wavelength of choice as this is where water absorption is strongest and an application where many users try to utilize a SWIR camera. Figure 2 shows the SNR with low flux of $0.8mW/m^2$ at 1400nm on the imager versus various integration times, which can be corelated to frame rates.

[1] https://en.wikipedia.org/wiki/File:Photon-noise.jpg

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As one can see, the PIRT imager has a favorable factor of 6X higher SNR at 30Hz versus the CQD device. PIRT's SNR is approximately 27 while the CQD's SNR is approximately 4 and the 5µm pitch camera is only at 1.8. In this case, 30Hz was used as the flux is low so a longer integration time is desired. This SNR difference is very significant when computers are analyzing the image. Larger SNR puts less strain on the computational system and makes detection much easier. At 100Hz, PIRT's SNR is 9.4 while the CQD has a 1.9 SNR. At a SNR of 1.9, a human has difficulty imaging the object and the features around it, (i.e. Figure 1 would make seeing the small rocks tough to detect at an SNR of 2 versus 10). The other competitive SWIR camera, a 5µm InGaAs camera, has an SNR of 0.6, which makes it nearly impossible for a human to even detect the object in question, i.e. the little rocks around the big rock at the top of Figure 1.

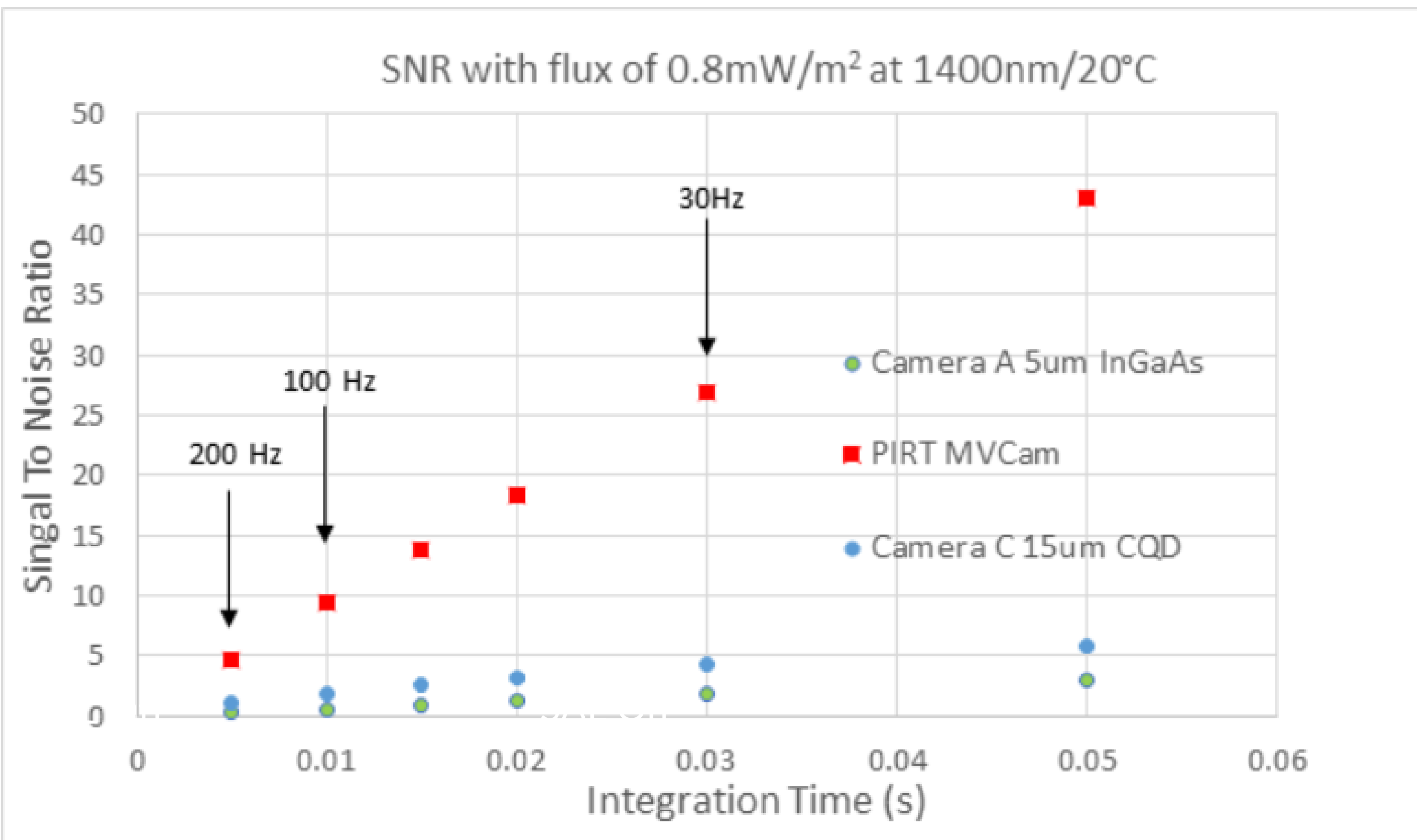

Figure 2. SNR versus integration time for three different cameras showing the advantages of PIRT's camera over lower cost cameras at low light levels.

Figure 3 is a similar graph, but at elevated light levels of 40 mW/m^2. PIRT's camera is still superior for sensing with significantly higher light levels. Using the 200Hz higher frame rates with large amounts of light, the PIRT camera has a SNR of 227 versus a SNR of 15 for the competitor's 5μm small pitch InGaAs sensor at the same light level and integration time. This difference can determine if algorithms work well or fail to detect the issue at hand. This SNR delta can also influence detecting moisture levels on a sample or a contaminant rushing by on a conveyer belt.

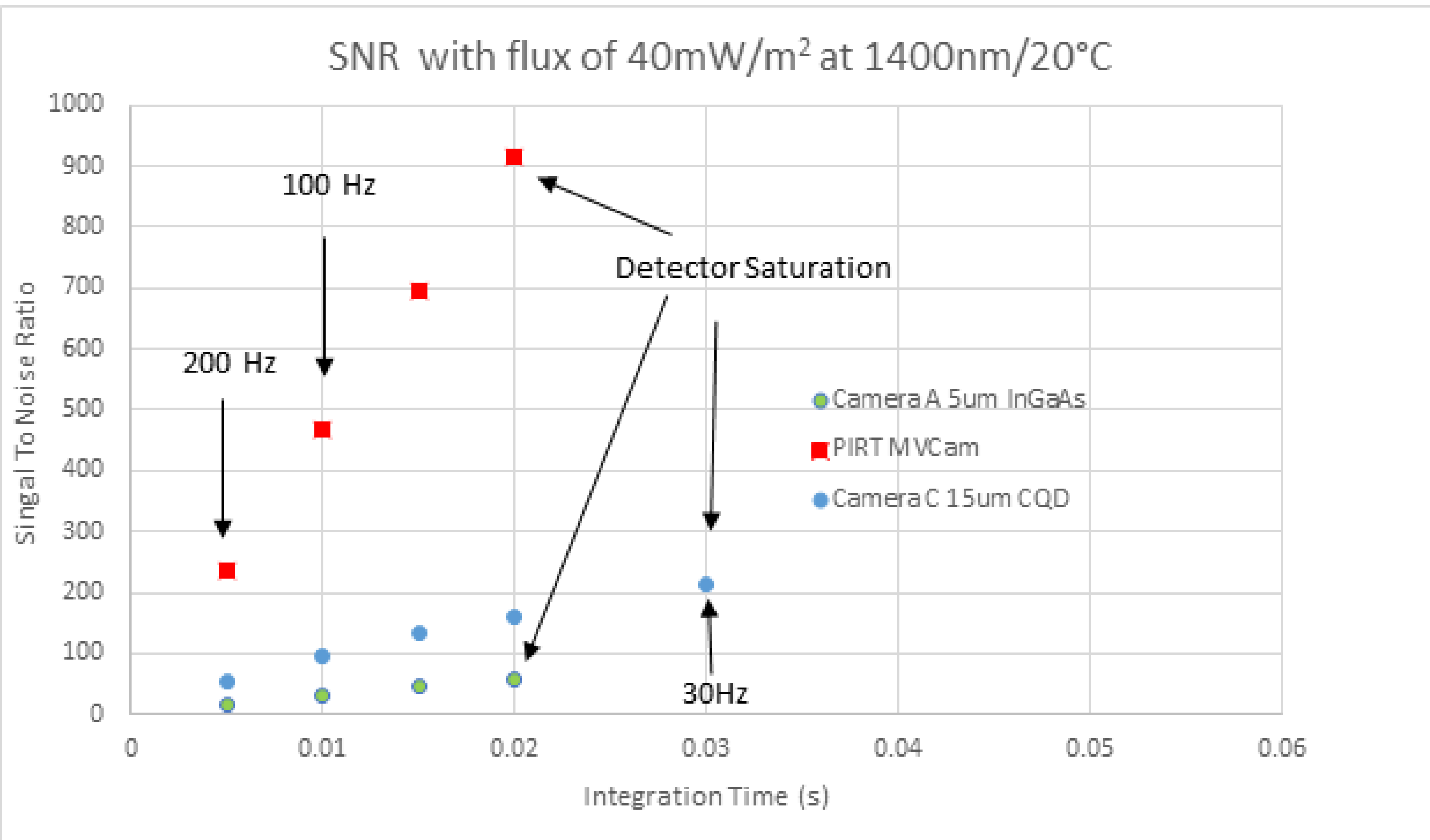

Figure 3. SNR versus integration time for larger signal flux on the same three cameras as Figure 1 still showing PIRT's significant advantage in SNR.

Pixel Pitch Effects

Small pitch InGaAs cameras have the advantage of lower cost, but each pixel is collecting significantly less light. This factor, combined with the higher read noise of these imagers, leads to a camera that is significantly less sensitive. A 12μm pitch camera can capture nearly 6x more light than a similar 5μm pitch camera. A 5μm pitch camera generally has a less complicated amplification structure leading to higher read noise. This higher noise from 5μm devices makes the SNR difference even more favorable for the PIRT imagers, which has on average a 6x advantage under normal conditions. In the example above, the sensitivity difference of a PIRT imager is more than 18x combining the read noise and pixel pitch!

CQD devices, as stated earlier, have poor QE that leads to a 10x less sensitive device. CQD manufacturers attempt to make up for this disadvantage with larger pixels. An InGaAs imager using a 12μm pitch has 64% less collection area versus a 15μm pitch CQD. However, this is not nearly enough to make up for 10x difference in QE, which is why PIRT's InGaAs sensors show a 6x improvement in SNR over CQD detectors. PIRT's InGaAs imagers also have less dark current than the CQD detectors, which further increases the SNR difference for longer integration times.

Conclusion

The signal to noise ratio of a SWIR camera can make all the difference in detection and between seeing or not seeing the object in question. This is especially true at high frame rates where SNRs are limited by the short exposure times. SWIR imagers have unique detection properties, but without the right sensitivity the imager will not be able to leverage these unique abilities. PIRT's cameras are built for both sensitivity and speed while providing a wide 14-bit dynamic range. We even have cooled cameras that significantly reduce the dark current to allow for longer exposure times, up to 3 minutes, when you are looking at very low photon flux. This camera is used in astronomy because their photon flux is very low and they conduct very long integration times, up to minutes at a time. Please give us a call as we would be happy to demonstrate the advantages of high sensitivity SWIR cameras and imagers.

GET IN TOUCH

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