R&D and industrial applications for Near Infrared (NIR) cameras

Near infrared (NIR) cameras, which are sensitive to the near-infrared spectrum (0.9 to 1.7 µm), are increasingly found in research laboratories, design departments and on factory production lines. NIR cameras have many advantages. Not only can they be used to view phenomena that cannot be observed with infrared cameras that are sensitive to mid-wavelength infrared (MWIR) and long-wavelength infrared (LWIR) - respectively 3.0-5µm and 8-12µm - NIR thermal imaging cameras also require no cryogenic cooling, which makes them lighter, smaller and less expensive.

The number of possible applications for NIR thermal imaging cameras is vast. This article presents just a few of the major applications for which NIR thermal imaging cameras are particularly well-suited, but the use of these cameras is by no means limited to the applications mentioned.

FLIR SC2500-N

Most NIR thermal imaging cameras have an InGaAs (Indium Gallium Arsenide) detector that can be used without cooling, although in some cases a Peltier effect module is used. Since these cameras have no moving parts, they are particularly robust and capable of withstanding harsh conditions and continuous 24/7 operation.

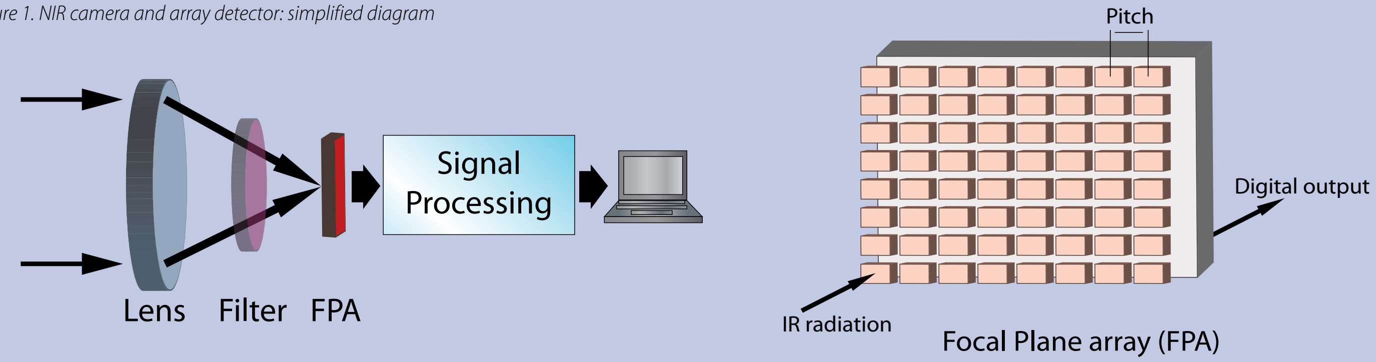
NIR cameras: operation and specific characteristics

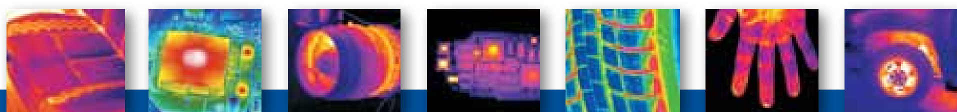
NIR cameras are very similar to traditional CCD cameras. Figure 1 shows a simplified diagram of a NIR camera and an array detector.

Key components:

- **Optical lens:**
  The optical lens concentrates the light flow on the surface of the detector and contributes to the formation of the image. For NIR cameras optics corrected over the entire 0.9 – 1.7 µm spectrum are best for optimal image quality;
- **Filter:**
  In most of the NIR camera applications spectral selectivity is required to maximize the amount of useful information. In most cases this can be done with an interferential filter, which allows only specific parts of the NIR waveband to pass. For some specific applications a different filter might be required, but whether you need an interferential filter or a filter of another type, FLIR Systems can provide exactly the right filter for the application.
- **Detector:**
  The heart of the infrared camera is the detector, the component that detects and measures infrared radiation. Most NIR cameras have a detector made of Indium Galium Arsenide (InGaAs), which has a very high sensitivity in the NIR spectrum (0.9 to 1.7 µm). Another type of detector that is used sometimes is the Mercury Cadmium Telluride (MCT) detector, which is sensitive in the 0.8 µm and 2.5 µm part of the spectrum. This part of the spectrum is also called the short wave infrared (SWIR) spectrum. It should also be noted that there is also a modified version of the InGaAs detector on the market – known as the VisGaAs detector – that has a spectral sensitivity extending into the visible light: it covers the 0.4 – 1.7 µm spectrum. Currently most detectors come in a version that consists of a Focal Plane Array of 320x256 pixels with a 30 µm pitch.
- **Electronics module:**
  The electronics module processes the signal from the detector and applies corrections such as on-camera non-uniformity corrections, but it also enables a certain number of operations, such as external triggering to synchronize the image capture with even the most fleeting of events.
- **Connections:**
  The connection commonly used nowadays for NIR cameras is GigaBit-Ethernet. Other types of connections, in addition to communications and control, are also available, such as a Trigger In/Out connection for the camera to control or be controlled by an outside source, a Lock-In connection for applications requiring synchronous demodulation and an analog video output that can be displayed on any video screen.

Figure 1. NIR camera and array detector: simplified diagram





Applications
NIR and SWIR cameras are used in so many applications that it would be impossible to list them all in this article. Their use is therefore not in the least limited to the applications described here. There are, however, a number of applications sufficiently well-known and integrated in various industrial processes or areas of research that they can be cited as good examples of the potential of these imaging systems

R&D Applications
Because most materials have characteristic attributes that can be seen in the NIR and SWIR spectrum, research laboratories often use NIR and SWIR cameras to determine certain physical or chemical properties of these materials.

This article addresses the following examples:
- *Imaging through certain coatings: infrared reflectography,*
- *Biochemistry / pharmacology: NIR/SWIR spectroscopy.*

Imaging through coatings: infrared reflectography
Infrared reflectography is a method used to investigate drawings beneath oil paintings that was developed in the 1970's. In addition to providing documentary evidence for archives, this technique also helps settle issues relating to the attribution of works of art.

This non-destructive expert investigative technique, used by many museums and art research centres, is based on the optical properties (diffusion and absorption) of pigments in the near-infrared range.

The example on this page involves a painting by Hans Memling entitled Triptych of Jan Crabbe (Musei Civici di Vicenza) and, in particular, a detail in the scene showing John the Baptist and a monk (figure 2).

Analysis of the underlying drawing using reflectography shows that the artist tried several approaches (positioning of the monk's head and John the Baptist's right hand – figure 3).

Figure 4 provides an overview of the principle of near-infrared reflectography.

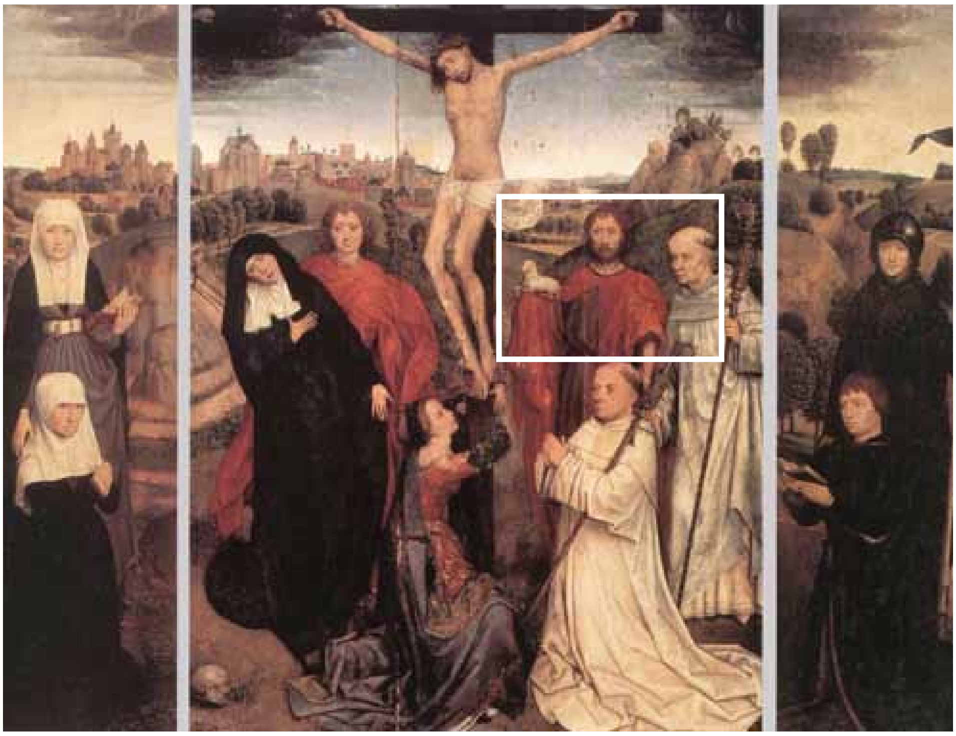
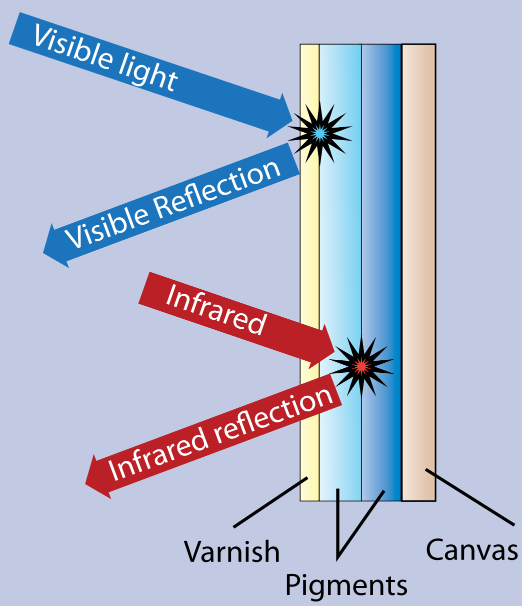


Figure 2. Triptych of Jan Crabbe by Hans Memling (Musei Civici di Vicenza)

Figure 3. Triptych of Jan Crabbe by Hans Memling (visible and near-IR spectrum)

Figure 4. Analysis of a painting using near-IR reflectography and comparison



Visible light passes through the varnish and as it comes in contact with the pigment part of the visible light spectrum is absorbed and the rest is reflected, resulting in the colors the human eye perceives. A part of the infrared radiation in the NIR / SWIR spectrum passes through the first layer of pigments, this allows for absorption and reflection at underlying pigment layers. This allows researchers to see what's below the top layer and look what's painted underneath.

An interferential band pass filter is almost always required because the absorptive properties of the pigments are spectrally variable. The longer the wavelength in the infrared, the deeper the camera "sees". Paint layers become thinner as the wavelength increases, thus allowing for underdrawing, hidden signatures, cracks... visualisation.

Biochemistry / pharmacology: NIR / SWIR spectroscopy
NIR / SWIR cameras with a focal plane array can be used to determine the spectrum of an object or extended component with spatially variable spectral properties (variable composition, localised active components, etc.). For rapid results and greater versatility, the camera should be used with an acousto-optics tunable filter (AOTF) or liquid crystal tunable filter (LCTF), or with an interferometer, depending on the precision of measurement required. Each mono-element in the array (pixel) in this case acts as a multi-spectral detector. A three-dimensional reconstruction can then be made as a function of the wavelength and transmission. NIR / SWIR spectroscopy can be used to measure humidity in a solvent (ethanol, for example) or to determine concentrations of OH-, CO_3^{2-} and HS- ions in an aqueous solution.

In pharmacology, these imaging systems can be used to carry out non-destructive investigations on tablets (to determine the presence or absence of an active ingredient, for example).

Figure 5, for example, shows measurements carried out on samples of isopropanol (rubbing alcohol) and natural spring water.

Industrial Applications
In industrial applications NIR and SWIR cameras are used for the development of new products and for quality control during the production process. Often the camera has to be integrated in a large and complex system.

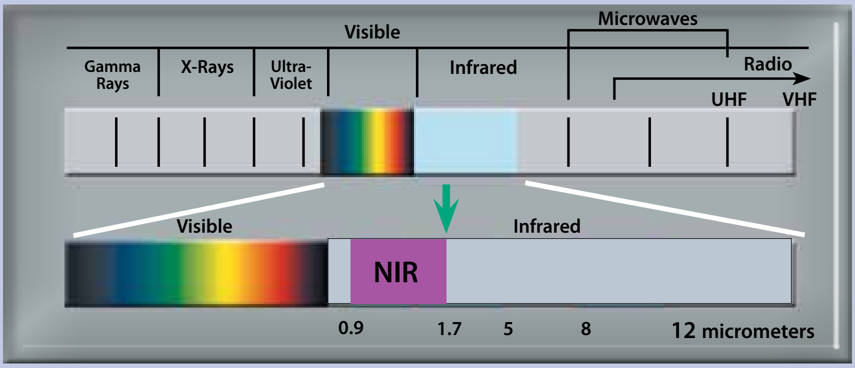
FLIR Systems: thermal imaging cameras that make the invisible visible in the NIR wave band.

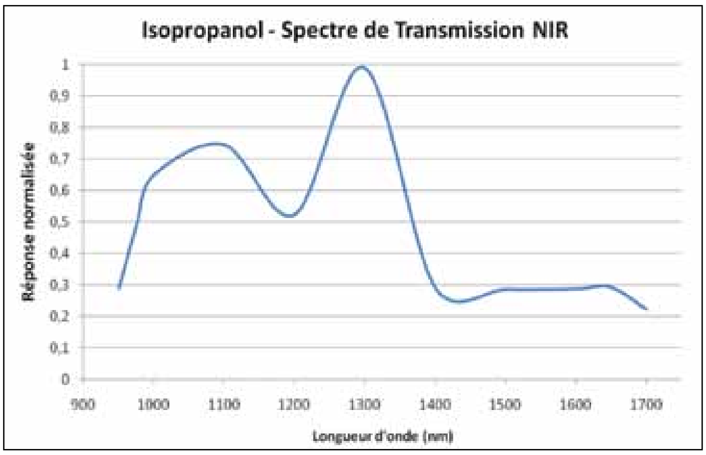
Being the market leader for thermal imaging cameras FLIR Systems also markets a full range of products that are making phenomena visible in the NIR waveband.

The FLIR SC2500-N thermal imaging camera provides an extraordinary sensitivity in the NIR part of the infrared spectrum. Its unique cut off spectral sensitivity at 1.7 µm makes it perfect for many applications such as laser beam profiling, drug concentration evaluation, seeing through blood and paint, performing spectra data collection of chemicals, food inspections, furnace temperature measurements, to name just a few examples.

Choice of detector
The SC2500 is usually equipped with an Indium Gallium Arsenide (InGaAs) detector that operates in the 0.9 to 1.7 µm (NIR) waveband. It can also be equipped with a Mercury Cadmium Telluride (MCT) detector that operates in the 0.8 to 2.5 µm (SWIR) waveband.

The FLIR SC2500 provides accurate noncontact temperature measurements. The camera is able to be calibrated for temperatures up to 3000˚C.





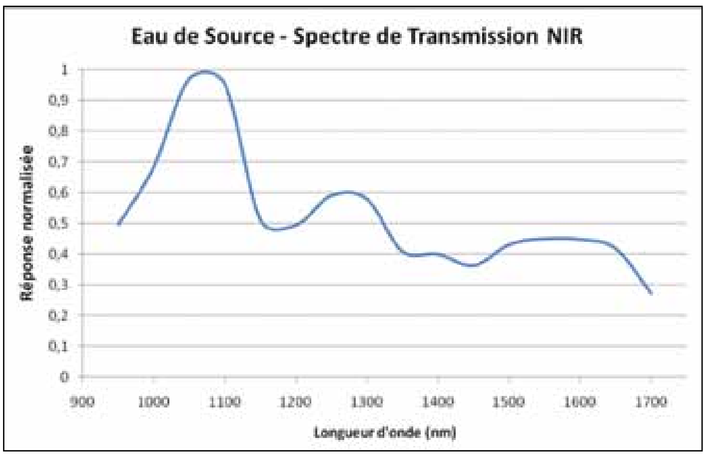


Figure 5. Isopropanol (left) and natural spring water (right) - NIR transmission spectrum measured with an InGaAs camera and a variable liquid crystal filter

Two examples will be described in this article:
- high-temperature thermography,
- inspection and detection of bruises in the agri-food industry.

High-temperature thermography

Most of the R&D applications of NIR and SWIR cameras mentioned above are based on reflective properties of materials, not on the emitted heat. The reason behind that is the connection between temperature and wavelength. Every object with a temperature that is higher than absolute zero (–273.15°C) emits electromagnetic radiation and the warmer the object is the more electromagnetic radiation it will emit. Most of this electromagnetic radiation falls within the infrared spectrum. By determining the amount of emitted infrared radiation the temperature of the object can be determined, a method called thermography. A rise in temperature has more effects than just the increase in the amount of electromagnetic radiation emitted, however. It also affects its wavelength: in general the higher the temperature is, the shorter the wavelength becomes.

Traditionally thermographers use infrared cameras that operate either in the mid-wave infrared (MWIR) or long-wave infrared (LWIR) spectrum, which are also known as thermal imaging cameras. These thermal imaging cameras are not very accurate if the temperature of the object is very high, because of the above-mentioned change in wavelength. Therefore NIR and SWIR cameras are much more accurate if the temperature of the object rises above 400°C.

Figure 6 shows two temperature measurements, of a black body at 800°C and 1050°C, and the precision of these measurements.

Figure 7. NIR cameras ar widely used for inspections and bruise detection in the food industry.

Inspection and detection of bruises in the agri-food industry

Like most other fruits apples are quite fragile. If an apple is damaged, so-called bruises will appear on the apple's skin. If a cell is damaged it gets filled with water and appear brown after some time. These so-called 'bruises' have a very negative impact on the appeal of the apple to the customer, so in the fruit industry these bruises are considered a key quality indicator of the fruit grade.

Because water is highly absorptive in the NIR part of the spectrum, a NIR camera with dedicated spectral filtering can be used to detect bruises at an early stage, before they can be detected with the human eye or with visible CCD/CMOS cameras.

Figure 7 shows two images of an apple, one picture taken with a normal visual light camera and the other taken with a FLIR SC2500 NIR camera with a 900-1150 nm band pass filter. Both pictures were taken at the same time, shortly after the apple was purchased. On the image taken with the NIR camera the future bruises show op very clearly, while the visible image shows no signs of damage.

In some applications Electron Multiplying Charged Coupled Device (EMCCD) cameras are used for similar purposes. EMCCD cameras are basically visible light cameras that have little sensitivity in the NIR spectrum. NIR and SWIR cameras are much more sensitive to this part of the electromagnetic spectrum, however. Their high quantum efficiency between 900 and 1100 nm (over 75%), makes them the best choice compared to Electron Multiplying Charged Coupled Device (EMCCD) cameras, which have a quantum efficiency at these wavelengths of less than 20%.

Conclusion

NIR and SWIR cameras are often used in laboratories, R&D departments and to some extent, on process control lines. Easy to integrate, easy to run, these cameras have opened a new world of exciting investigation.

The range of applications for NIR cameras is huge, and it is getting broader every day. The fact that FLIR Systems has almost 10 years of experience in the design and fabrication of InGaAs detectors and NIR cameras, and in that time has built up an extensive amount of knowledge in this field, makes FLIR Systems a first-rate partner for the development of NIR or SWIR camera applications.

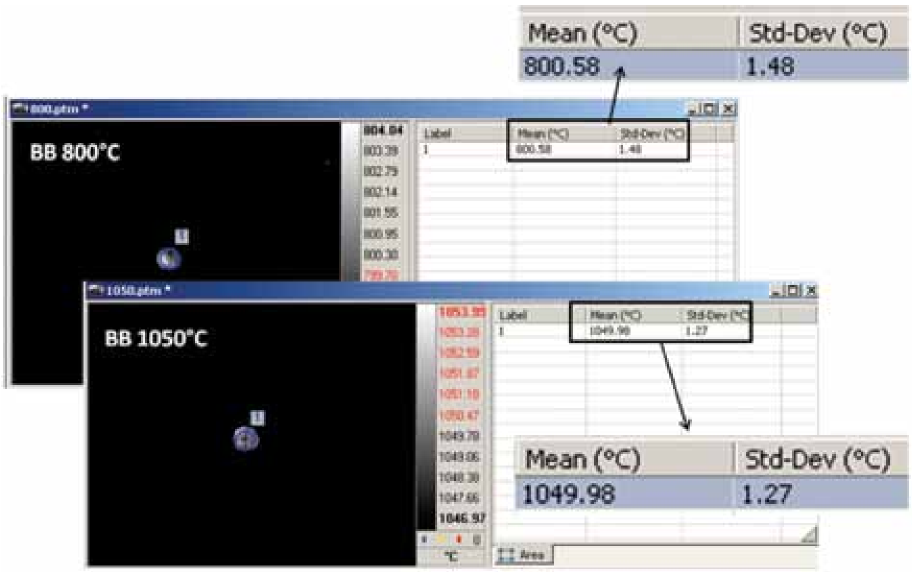


Figure 6. Counter-measurements on a black body at two temperatures (800°C and 1050°C). Note the precision and low dispersion of the measure

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