cygnus Business Media

ADVANCED IMAGING

By Douglas Malchow, business development for commercial products SUI (Sensors Unlimited, Inc.), part of Goodrich Corporation (Princeton, N.J.)

Imaging in the Shortwave Infrared (SWIR) for Industrial Applications

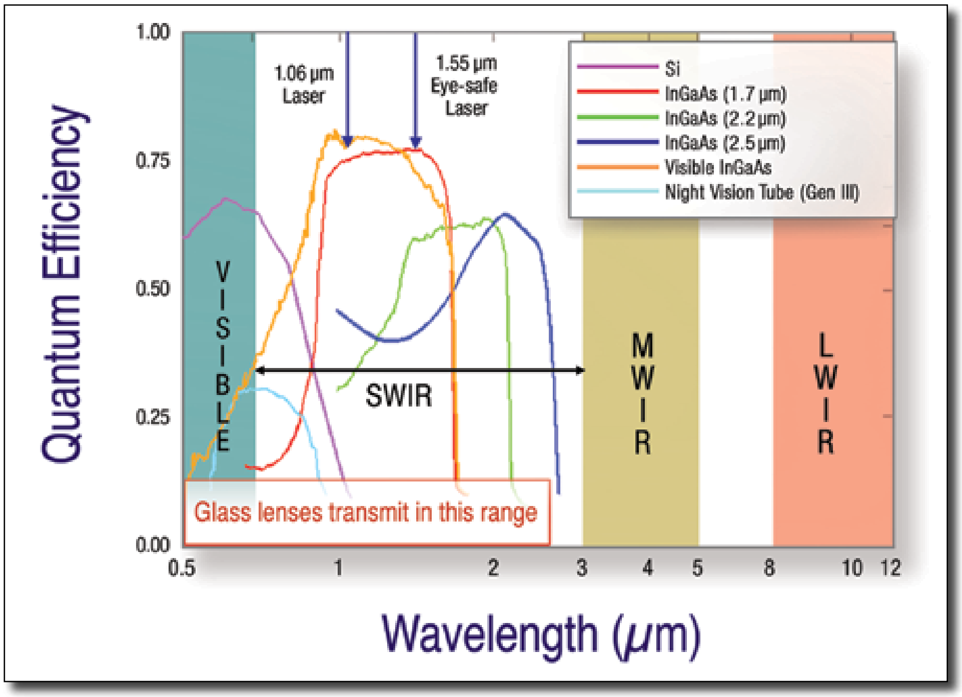

Fig. 1 - Quantum Efficiency Graph

When visible imaging comes up short, SWIR can be the answer

- Shortwave infrared
- Machine vision
- UV, SWIR, MWIR, LWIR
- SWIR industrial applications
- Specular reflectance
- Spectral analysis

Fig. 2 – Visible apple image (left) and SWIR apple image (right) clearly shows bruising

Visible-camera machine vision of industrial processes saves time, money and resources for manufacturers all over the world. Identifying drift in a manufacturing process at the point of origin saves millions of dollars in scrap product down the line. But what do you do if the production of goods you are trying to control provides no observable or visible cues for monitoring the process or detecting defects? The challenge to the process engineer is to find viable alternatives that will work with the inspection infrastructure that already exists.

This article explores the use of invisible light to solve some everyday industrial imaging challenges and illustrates the method by developing a solution for imaging the placement of white glue on white cardboard boxes.

INVISIBLE LIGHT

The human eye generally responds to light with wavelengths from 380 to 720 nm. Visible light cameras can be filtered to match the eye response, including imaging in color. These cameras are the dominate type used in machine vision systems because, in most cases, they will capture the product or process characteristics that are essential to the product quality. Outside this spectral range, the light is invisible to the eye, with wavelengths below 400 nm referred to as ultraviolet (UV) and those above 700 nm as the infrared (IR). The infrared spectrum is further broken down into sub-sections: near-infrared (NIR) or short-wave infrared (SWIR), mid-wave infrared (MWIR) and long-wave infrared (LWIR), as illustrated in Figure 1.

INVISIBLE LIGHT CAMERAS FOR MACHINE VISION

Light from the UV, NIR and SWIR wavelength bands interact with surfaces in much the same way as visible light, so system integrators can set up machine vision systems for these wavelengths in the same way they would set up for visible-responding systems. Compact, un-cooled cameras for these bands are readily available with standard Camera Link® interfaces for machine vision applications and are easy to use. The same illumination concepts apply for both visible and the UV, NIR and SWIR bands; it is important to use diffuse light and avoid direct reflections of the surface of the objects into the camera.

LWIR cameras primarily respond to the thermal emissions of objects in the scene, while MWIR cameras can be used for thermal or reflected light applications. These cameras require cryogenic operating temperatures, creating reliability and power consumption concerns for industrial applications. Uncooled LWIR cameras are available for temperature uniformity applications and monitoring machinery for hot-spots.

Both MWIR and LWIR cameras cannot see through glass windows and need lenses made with exotic materials, limiting the flexibility of system integrators for matching cameras to the available working distance and field-of-view requirements for industrial applications. UV sensitive cameras usually cover the visible to NIR wavelength bands as well, as they are also based on silicon technology. However, they also require special lens and window materials. As a result, optical components for many of these invisible light cameras are expensive and in limited supply. In contrast, SWIR and NIR responding cameras can use the large variety of standard photographic or CCTV lenses available in the commercial market.

At the heart of visible-responding cameras are silicon based detectors, based on CCD or CMOS technologies. As previously mentioned, these are normally filtered to match the eye response curves. Without the filters, the wavelength response of these detectors extend out past 700 nm to beyond 1000 nm—a region their manufacturers refer to as the near-Infrared. Some coatings, inks and dyes become transparent in this range; these unfiltered silicon cameras can be used to 'see' under these layers to monitor the alignment of the top coating. Or, when a protective coating is applied over graphics, and therefore transparent to a visible-responding camera, the NIR responding camera sees the coating with enough contrast to monitor coating uniformity and placement.

With SWIR-responding cameras, imaging beyond 1000 nm improves upon this capability to 'see' transparent coatings. Many underlying graphics designed for the human eye use inks that become transparent at longer wavelengths, while some coatings become viewable. This allows SWIR cameras a greater ability to discriminate between layers or to capture coating uniformity than is possible with other wavelength bands. Water-based coatings are an example of this, as they absorb light at several wavelengths in the SWIR. Later in this article, examples of imaging water based glue will illustrate this application.

Affordable SWIR cameras, operating at room temperature, use detectors based on Indium Gallium Arsenide (InGaAs) technology, combined with CMOS readout integrated circuits (ROIC). These cameras are as compact as visible-responding machine vision cameras, and utilize a common computer interface for easy integration into process control systems. Cameras are available off the shelf with detector arrays of 2 dimensions (also known as area or matrix cameras) or 1 dimension (also known as linear or line-scan cameras). Though pixel sizes are not as fine as visible cameras, effective image resolution is competitive and superior to the thermal detectors whose resolution is limited by the long wavelengths themselves.

SWIR INDUSTRIAL APPLICATIONS

Practical application of invisible-light imaging ranges from separation of raw agricultural products from fragments of the packaging, to high tech alignment of fiber optic components or inspection of semiconductor circuits through the silicon substrate. For instance, agricultural leaf products are often bundled with rubber straps. If the rubber straps break or fragments are introduced into the process, they could contaminate the machinery, production might stop, resulting in expensive damage to the equipment or the cost of a lost production.

By imaging at varying wavelengths, several different types of contamination can be monitored and rejected. Similarly, rice grains can be screened for dirt, glass or leaf. In other agricultural processes, stems are being separated from leaf by imaging the differences in moisture content. Fruit and vegetable inspections with SWIR cameras can detect and reject bruised fruit (Figure 2).

Spectral inspection of recycled plastics is currently employed extensively in Europe to identify and sort the various types of plastic used in consumer packaging such as PET, PMMA, PVC and PDM. By use of an imaging spectrometer in front of the camera, along with diffuse illumination of the objects on the conveyor belt, material composition can be identified remotely as the trash moves on the conveyor belt. Air jets then sort the bottles or containers into the appropriate collection bins. Properly sorted plastics result in more valuable recycled goods and municipalities can then sell the premium product to material processors for top dollar.

Pharmaceutical manufacturers have compelling requirements to ensure that products provide the correct amount of medicine, with the correct coatings, and that the correct medicine is in the appropriate package. NIR spectroscopy with SWIR cameras allow remote monitoring of pills and/or other medicines through the packaging, making these imaging systems very effective for final inspection.

Hot glass processing plants are using SWIR cameras to inspect bottles coming out of the molds because they can monitor size, shape and defects, both inside and outside the bottle. With calibration, they can also monitor temperature. This permits the manufacturer to catch any problems with the glass molds at the source, before thousands of defective bottles are produced. More importantly, identifying a glass mold defect and removing it from the line helps ensure that no bits of broken glass create a hazard in a consumer product.

Another hot process monitoring application is inspection of industrial furnaces used for chemical recovery. SWIR cameras can inspect through glass safety windows and/or standard glass optics (which would block thermal cameras), yet are able to "see" through swirling smoke particles better than visible cameras. (Small particles scatter visible light, while the longer SWIR wavelengths are able to penetrate clouds of dust or smoke; this also gives SWIR an advantage when imaging long distances through the atmosphere).

A new imaging technique called optical coherence tomography shows promise for high resolution SWIR imaging for a few millimeters through opaque, scattering coatings. It is based on optical interferometry, spectral dispersion and computer tomography, and is being developed by the bio-medical community for imaging through tissue. It is beginning to be applied to industrial inspection in the lab and holds promise for the future as computing processing power increases.

Fig. 3 – Experimental Setup

IMAGING EXAMPLE

To illustrate a real-world example of solving a machine vision challenge with SWIR imaging, we will now focus on detecting the placement of white adhesive on a white cardboard box prior to the folding and assembly step. The challenge is to detect unglued or weakly glued box flaps, to identify unsightly or unwanted glue on visible surfaces and to prevent gluing of flaps meant to open easily while also reducing excess glue consumption. Standard visible cameras, color or monochrome, see little contrast between the white glue and the white cardboard.

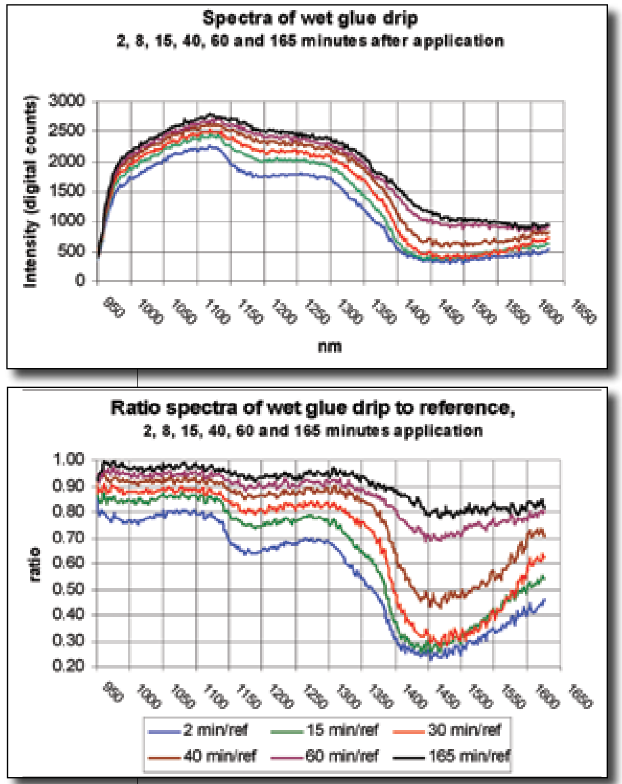

Fig. 4: Top – Raw spectra taken at several times after glue drip reached field of view

Bottom– Spectral response normalized by spectra from white box adjacent to drip

Glue used on paper products is typically water-based and we know that the water molecule has strong absorbance lines in the sensitivity band of uncooled SWIR cameras made with standard InGaAs detectors. But to provide a method for use with unknown materials, we will discuss using an imaging spectrometer to identify the best wavelengths for imaging, then using filters to improve the contrast. The basis for this test method is known as diffuse reflectance NIR Spectroscopy. It consists of comparing the amount of light reflected from the materials in question as a function of wavelength. With this information we can identify the substances, and many times, determine its relative concentration. Or, as in this example, simply determine the best filter wavelength to discriminate between two substances.

LIGHTING IS CRITICAL

Key to obtaining good results is achieving uniform and diffuse illumination of the materials. We want the light to penetrate into the bulk of the materials we are trying to discriminate between, which in this case

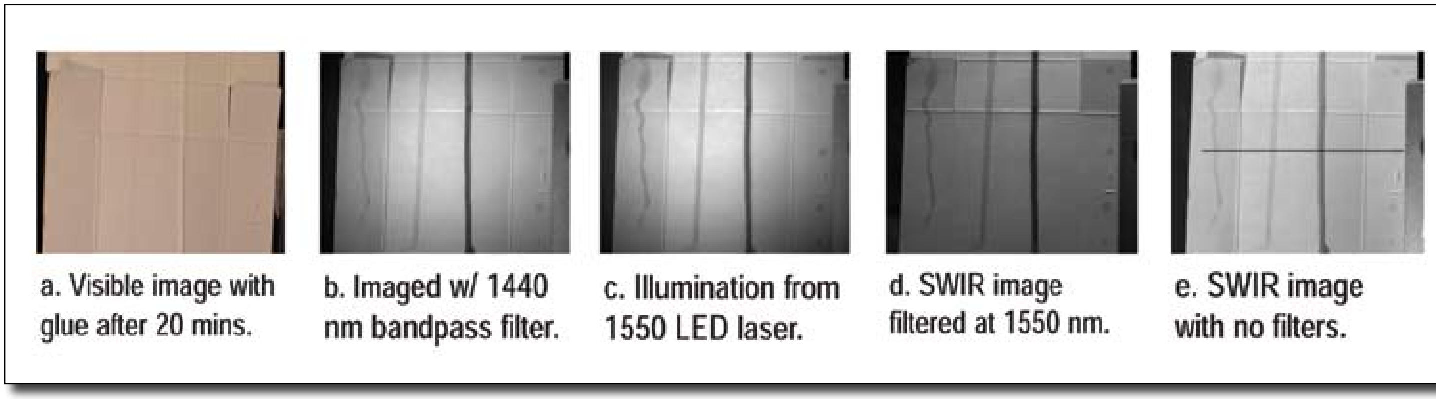

Fig. 5 – (left to right) a)Visible image with glue, after 20 minutes; b) Imaged with 1440 nm bandpass filter; c) Imaged with illumination from 1550 LED laser); d) SWIR image filtered at 1550 nm.; e) SWIR image (no filters)

is the glue and the cardboard. The more the photons interact with the molecules of the substance, the more the molecular absorbance will result. If light reflects just off the surface, the path length where light interacts with the substance is short and it has little effect on the reflected light. This is referred to as specular reflectance; this will be apparent many times as a mirror-like reflectance in the image. This shows up as extremely bright 'hot' spots or 'glints' of the light source and usually dominates the image. So the aim is to position the light sources at angles which do not reflect directly back into the camera. This can be quite challenging, especially if the surface being monitored is shiny and has many surfaces at a variety of angles. Using multiple light sources with diffusers, to yield a general glow from many different points, can help overcome the effects of specular reflectance.

EXPERIMENTAL SETUP

For this article, a plain white cigarette box, prior to folding, was the object of the test. White school glue was placed as dots, a squiggle or dripped down the length of the box in several tests. A fresh drop was added to the box so spectra and images could be taken periodically while the glue was curing to identify which wavelengths were unique to the moisture in the drop.

Two incandescent lamps were used to illuminate the box, one a 50 W quartz halogen over the cardboard box, the other a 100 W desk lamp that was below and to the side of the box and cameras (Figure 3). As the imaging spectrometer only passes a few nanometers of light energy to each pixel, high light levels are needed to obtain good signal to noise across all of the wavelengths of interest. The spectrometer used in this example was the ImSpector from SPECTRAL IMAGING LTD. (Oulu, Finland). It was mounted on a SU320MS-1.7RT camera from SUI, Goodrich Corp., with a 25 mm f1.4 lens on the input. The combination captures a spectrum on each of 320 columns of the camera's focal plane array (FPA); it images the wavelengths of 920 to 1620 nm across the 256 vertical lines of the FPA's height. To ensure accuracy of the spectra, a Xeon pen lamp in a stand, shown to the right of the white card in the picture, was used to calibrate the spectral axis.

A SU640SDV-1.7RT camera was also used, with a 50 mm f/1.4 lens, to capture 2D SWIR images of the glue on the white box. Two bandpass filters, one with center wavelength of ~1400 nm and bandwidth of ~90nm, the other centered at ~1550 nm, with bandwidth of ~20 nm, were used in front of the lens to capture images in different wavelength bands to show the increased contrast they bring to machine vision of water based materials. In addition, a 1550 nm LED array was used to provide illumination from 1510 to 1590 nm to demonstrate a viable alternative to using hot incandescent lamps. This array, from Stocker-Yale (Salem, N.H.), consisted of 100 chips behind a lens producing a flood lamp with a 30 degree angle of illumination.

SPECTRAL ANALYSIS

The accompanying graphs show the spectra captured on the drip, with the first graph showing raw data taken at 2, 15, 30, 40, 60 and 165 minutes after the drip crossed the slit image plane of the spectrometer (Figure 4). Differences are shown at all wavelengths, but it is difficult to separate unique changes against the strong spectral variation due to the lamp output, moisture in the air, and the spectrometer. It is easy to isolate the system response by normalizing the spectra of the drip with the spectra of the white box before the glue covered it. The second graph demonstrates this, with the clear result showing broad absorbance at 1000, 1190 and 1430 nm, and the strongest response at 1430 nm. It is also clear that, even after drying completely, the glue exhibits residual absorption at all wavelengths past 1400 nm (Figure 5).

This is quite apparent when looking at the SWIR images, comparing the cases with or without filtering or with selective wavelength illumination. The old glue (ranging from two weeks to 9 months old), is clearly darker than the cardboard in all of the images. With a little contrast enhancement, machine vision systems would easily be able to measure the glue locations and amount applied, while also verifying cure time.

CONCLUSION

SWIR imaging and spectroscopy helps manufacturers around the world solve challenging quality control and yield optimization problems. By working with system integrators who understand illumination and cameras, and spectroscopists who understand the product chemistry, robust solutions will be implemented that quickly payback the investment. ***AI***

GOODRICH

SUI (Sensors Unlimited, Inc.), part of Goodrich Corporation

3490 Route 1, Building 12
Princeton, NJ 08540-5914
Phone: +1 609-520-0610

Fax: +1 609-520-0638
Web: www.oss.goodrich.com/sui
Email: sui_info@goodrich.com

Reprinted with permission from ***Advanced Imaging*** magazine • February 2007