MACHINE DESIGN

Short-wave IR imaging invades machine vision

SWIR imaging brings a new dimension to machine vision, opening the door to a host of new applications.

Doug Malchow
Application engineer Sensors Unlimited Inc. Princeton, N.J.

Shortwave infrared (SWIR) imaging is quietly earning a growing place in machine vision for process control. SWIR imagers, sometimes referred to as NIR imagers, see objects and events traditional and thermal cameras cannot. They're also smaller and lighter than thermal cameras and cost far less than many of them. Furthermore, most InGaAs SWIR cameras are solid state with no shutters, cooling systems, or other moving parts. Some are set at the factory, so there's never a need for nonuniformity corrections (NUC) throughout their service lives. SWIR imagers work with plain glass optics, avoiding the need for silicon or germanium lenses found in thermal imagers and costing 10 times as much.


SWIR cameras classify polymers for sorting on recycling line in Europe.

Moreover, the installed base for InGaAs SWIR detection is rising steadily in both military surveillance and industrial imaging. Primary reasons for this are the compactness, low noise, and the simple operation of InGaAs cameras and arrays. These devices detect in the SWIR band with minimal cooling and electronic overhead, making the cameras similar in operation to silicon CCDs and CMOS imagers. With growing experience has come increased user confidence to use these cameras 24/7. SWIR-based machine-vision systems have proven successful, economically and technically, in literally hundreds of industrial applications. And they offer benefits thermal and visible-spectrum cameras do not, creating a performance/life-cycle cost advantage for SWIR, even in applications where both thermal and SWIR can technically do the job.

Like visible CCD and CMOS detectors, SWIR detectors use reflected light to generate high-resolution images. IR cameras, by contrast, sense heat only, producing lower-resolution images. Although InGaAs cameras and arrays are as simple to operate as silicon CMOS imagers, they look at a different wavelength band which has proven critical in many applications. InGaAs SWIR imagers can monitor a product's physical and chemical properties, giving process engineers more measures of product quality in fit, form, and function.

InGaAs-based SWIR cameras, unlike IR cameras and SWIR cameras with InSb or HgCdTe detector arrays, need neither shutters nor expensive cryo-cooling for the arrays. Eliminating these components increases reliability, lowers cost, size, and weight, and makes them relatively immune to vibration errors.

Other advances in SWIR technology include linear arrays with up to 1,024 pixels on a 25 µm pitch for more resolution and a wider field of vision, so fewer cameras cover more area. And today's InGaAs SWIR cameras can output analog and digital simultaneously as a standard feature.

Recently, for example, an InGaAs microcamera measuring only 5.9 x 2.8 x 1.7 cm—smaller than a Zippo lighter or package of Tic Tacs—and weighing only 70 gm was built for the military. It is an all solidstate camera with no moving parts to fail or need attention. It features factory-set NUCs and generates 12-bit digital video and RS-170 analog video simultaneously. Such cameras should be of interest for applications that must squeeze several cameras into small, hard-to-reach places. A machine-tool manufacturer might use such a camera to monitor axes while they are cutting. The small camera can monitor dimensions of the workpiece and sense overheating.

In the not-too-distant future, monitoring lasers in bands outside 900 to 1,700 nm will need extended-range InGaAs detectors. Because of growing military needs, this extended-range technology is scaling up to production volumes, lowering the cost for manufacturing applications. Soon, a single SWIR detector will add datacom laser wavelengths at 780 and 850 nm. In addition, new detectors will profile longer-wavelength lasers being developed in the 1,800 to 2,200 nm wavelengths for laser imaging detection and ranging (LIDAR). •

Alternatives to SWIR

There are certainly other imaging technologies than InGaAs and SWIR for machine vision. In fact, most applications still use CCD and CMOS imagers for high field-of-view, high-speed machine vision in the visible range. Thermal cameras are generally used for remote temperature measurement in industrial applications. Thermal and visible are complementary sensing ranges as each can see or find contrast between objects the others cannot.

There have also been advancements in all three camera technologies. All are now smaller, lighter, more sensitive, more rugged, have more features, and are lower in price. Microbolometers, for example, now image in the thermal range without cooling and yet cost less than SWIR cameras. They are moving from military applications to automotive night vision and may find a place in some machine-vision applications. However, they are slow, disqualifying them from high-speed, flash, or pulsed-illumination applications. Bolometers also need mechanical shutters and costly silicon or germanium lenses. CCDs and CMOS visible-range imagers have advanced as well. They now have smaller pixels, greater sensitivity, and a far lower cost.

Glassmaking

Manufacturers of glass hollowware have searched long and hard for a way to pick out defective bottles the “hot end” of their process, while the pieces are still between 200 and 700°C. At that stage, rejects can be shunted aside and reprocessed. Even more important, the process can be corrected before creating a mountain of scrap.

The false-color temperature profile of a wine glass taken with SWIR lets inspectors see all surfaces, not just the front or surface facing the camera.

It turns out that the peak performance of lattice-matched InGaAs SWIR cameras falls right within this temperature band. And SWIR works through glass, so SWIR cameras see into and through bottles in process, all from one side. As a result, SWIR-based machine vision using both 2-D (320 x 256) and 1-D (1024 x 1) element linear arrays are popular with container manufacturers around the world. InGaAs imagers can also be calibrated to accurately measure emissivity versus temperature, thus monitoring an object's temperature uniformity and cooling rate. With this data, factory managers can optimize their processes and prevent shattering due to uneven cooling.

So far, InGaAs cameras have uncovered a common internal defect in bottle forming. Sometimes the process creates a web of hairlike glass filaments that crisscross the inside of the bottle. When cooled and hardened, these filaments fracture into shards that fall to the bottom of the container. Because InGaAs cameras see through molten glass, they pick up temperature differences between the filaments and the bottle wall. This triggers an error signal that sends bad bottles offline for recycling and flags a need for adjustments on the production machine to correct the problem.

Melting metal

SWIR machine vision has become the technology of choice for improving yields during molten metal processing. Emissivity differences between hot metal and slag show up more clearly in the 900 to 1,700-nm bandwidth than the visible or IR. Those differences displayed in an image tell operators precisely when to end the process to maximize yields without contaminating the metal with slag. SWIR imagers work through glass, so cameras can monitor the 1,899 to 3,000°F process from within protective enclosures. The option to use glass windows makes this much more economical than using silicon, sapphire, or germanium windows necessary with thermal cameras. Users report that InGaAs SWIR cameras detect the end point of the process every time, which thermal imagers do not.

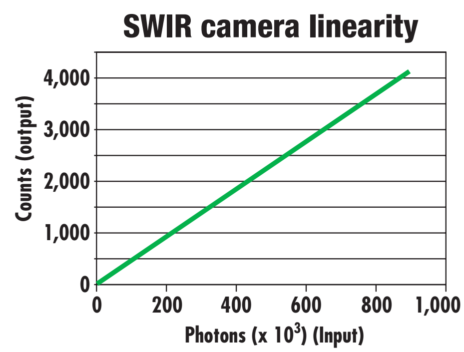
Lasers and chips

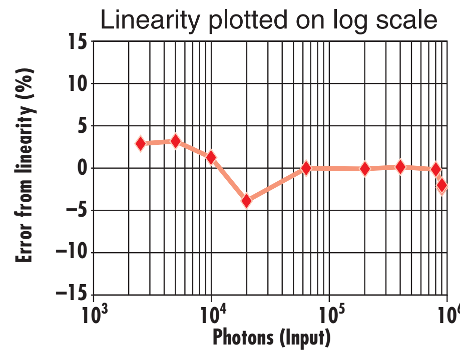
InGaAs SWIR imagers are playing important process-control roles in the manufacture of lasers, integrated circuits, and fiber-optic devices. Standard alloy InGaAs imagers check alignment in fiber-optic interconnects and analyze postproduction defects in semiconductor wafers. This alloy is the simplest to make, thus the least expensive, and can detect 1.55 and 1.3 µm light with a high signal-to-noise ratio. It is the highest s/n of all InGaAs imagers, making it the industry standard for monitoring fiber-optic interconnects.

A principal reason for SWIR’s prominent role in semiconductor production is that it “sees” through silicon. This is important in at least three applications. First, it lets SWIR image the wafer's surface, internal structure, mask alignment, and voids through the backside of the wafer as it moves through processing. Second, it can image photomask registration marks though the substrate, thus letting operators align optical elements such as lenses and fibers with devices or align layers of integrated circuits. And finally, many internal defects in ICs emit photons up to 1,300 nm in wavelength, while silicon substrates are transparent beyond 1,100 nm, thus operators can see postproduction defects by monitoring with photoemission microscopy. These same capabilities can be used to automate in-process machine-vision inspection in semiconductor and fiber-optic device fabrication.

Similarly, laser beam profiling gives manufacturers and their customers significant feedback. The telecom and datacom sectors use lasers with wavelengths of 980, 1,310, 1,480, and 1,550 nm, right in the heart of the InGaAs detector range. Similarly, the 1,064 nm wavelength has grown popular for a host of industrial, scientific, aerospace, and military systems. Laser manufacturers need to monitor their lasers' efficiency, wavelength, and optical dispersion patterns and map energy lost outside the beam. InGaAs has become the detector material of choice for laser profiling in the off-line mode, and is ready for use in automated fiber alignment.

Accurate laser profiling and mapping require an extremely linear detector,which is why Sensors Unlimited SU320M-1.7-RT SWIR camera is the industry standard.

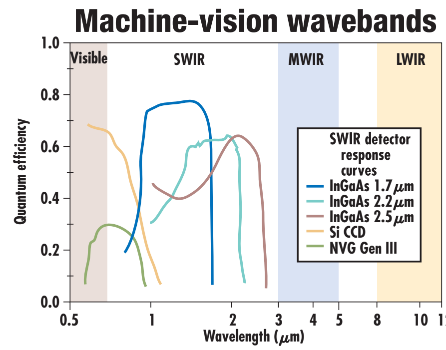




A flat-detection response is critical to laser profiling. InGaAs detectors, such as Sensors Unlimited SU320M-1.7-RT camera, have become the industry standard. It provides better than 1% linearity from 3 to 97% of full scale and better than 4% over 1 to 99% of full scale. This is far better than the 85% linearity available elsewhere.

Recycling

Beginning in Europe and now in the U.S., recyclers have come to depend on SWIR spectroscopy for sorting out useful plastics and other commodities from the waste stream. Inexpensive SWIR 1,024 x 1 or 512 x 1 line-scan cameras with wave length sensitivities ranging from 1,100 to 2,200 nm mounted on spectrographs identify the type of polymer in a container passing down a conveyer. Identification triggers a dam or paddle to divert the container into its proper bin.



A table of the wavebands for current machine-vision systems shows that various InGaAs formulations cover the entire SWIR range. A labeled bar across the bottom represents wavelengths that work through glass. Above that range, more expensive silicon and germanium optics are required.

Making medicine

In pharmaceutical factories, SWIR and hyperspectral spectroscopy systems monitor liquid fill levels within opaque containers. They also carry out real-time chemical analyses on products moving on belts or through pipes. For example, many liquid medicines go into white plastic bottles, making visual camera inspection of fill levels impossible. As water in the liquid absorbs light strongly in the 1,440 and 1,940-nm bands, a SWIR camera and incandescent backlighting of the vial easily reveals fill levels.

SWIR and NIR spectroscopy is often called on for real-time or continuous detection and measurement of water, proteins, carbohydrates, fats, oils, and various hydrocarbons. SWIR arrays are also being more widely used for NIR-Raman spectroscopy of coatings and tablet ingredients. SWIR cameras work well for Raman applications due to their linearity, broad dynamic range, sensitivity, and antiblooming characteristic. And in a new method to protect product authenticity, SWIR cameras monitor placement and readability of NIR fluorescing authenticity marks.

Keeping your feedstocks dry

Moisture is a key indicator of process control and quality in agriculture, textile processing, and forest-product industries. Water is opaque to SWIR illumination, so it can be measured with SWIR machines to gauge the health of crops, ripeness or dryness for processing, and the overall quality. Typical SWIR-camera formats for agricultural grading and sorting are 1,024 x 1 line scan and 320 x 240 area arrays.

Invisible bruises under the skin of an apple are revealed by SWIR imaging, helping food processors sort and grade produce. SWIR cameras detect differences in moisture inside fruit, which human sorters could never "see," and more cost effectively than thermal cameras.

Differences in moisture are often invisible to the eye. Thus, one key application has been sensing bruises under the skin of fruits and vegetables on a sorting line. Though suitable for processed foods, bruises are not acceptable in fresh produce. Another agricultural SWIR application is simply to gauge ripeness of picked fruits and vegetables on a conveyor belt. Produce growers can justify their investment in SWIR solely on the basis of maintaining a reputation for quality.

Likewise in dyed textiles, moisture content tells when a dyed fabric is dry enough for the next step, and whether dye coverage is correct. In particleboard manufacture, SWIR machine-vision systems measure moisture in chips to regulate downstream heating and drying.

In all of these examples, inspecting the purity of incoming feedstocks prevents contaminating expensive equipment. If raw cotton comes into a textile mill or wood chips into a lumber mill with pieces of plastic strapping mixed in, for example, it can cause millions of dollars of damage and lost product.