TRIEYE

WHITEPAPER

UNLOCKING INDUSTRIAL CHALLENGES WITH SWIR SENSING

INDUSTRIAL

TABLE OF CONTENTS

01 OPENING YOUR EYES TO SWIR FOR INDUSTRIAL USE

The constant demand to improve the reliability, efficiency, and performance of industrial processes is a driving force for the creation and integration of innovative technologies.

The latest industrial revolution, Industry 4.0, has promoted the automation and digitalization of manufacturing, providing higher yields at lower overall operation costs. To do this, vast amounts of data are collected by novel sensors and used to monitor operations, run diagnostics, and take action.

An increasingly significant part of this data is high resolution imagery which is analyzed by machine vision algorithms. Although optimization of these algorithms is constantly underway, the outcome is limited to the input data provided by the imagery hardware.

Continuous effort is invested in to finding ways to optimize the current capabilities of machine vision systems. The utilization of the **Short-Wave Infrared (SWIR) spectrum** holds huge potential to not only solve existing challenges but unlocking future industrial solutions.

> ***SWIR sensing systems offer advanced capabilities such as remote material classification and the ability to detect object that are indiscernible to the human eye and standard visible (VIS) cameras. They also enable the collection of rich actionable data under challenging visibility conditions like fog, smoke, or low-light.***

FIGURE 1: ILLUSTRATION OF VISIBLE TO SWIR LIGHT SPECTRUM WAVELENGTHS

WHAT IS SWIR?

Short-Wave Infrared (SWIR) refers to a wavelength range of 1-1.6µm, beyond what is visible to the human eye. Standard cameras usually operate in the Visible (VIS) and Near Infrared (NIR) spectrum, between 0.4-1µm.
Thus, the SWIR spectrum can be used for a number of applications that are not possible with VIS or NIR cameras.

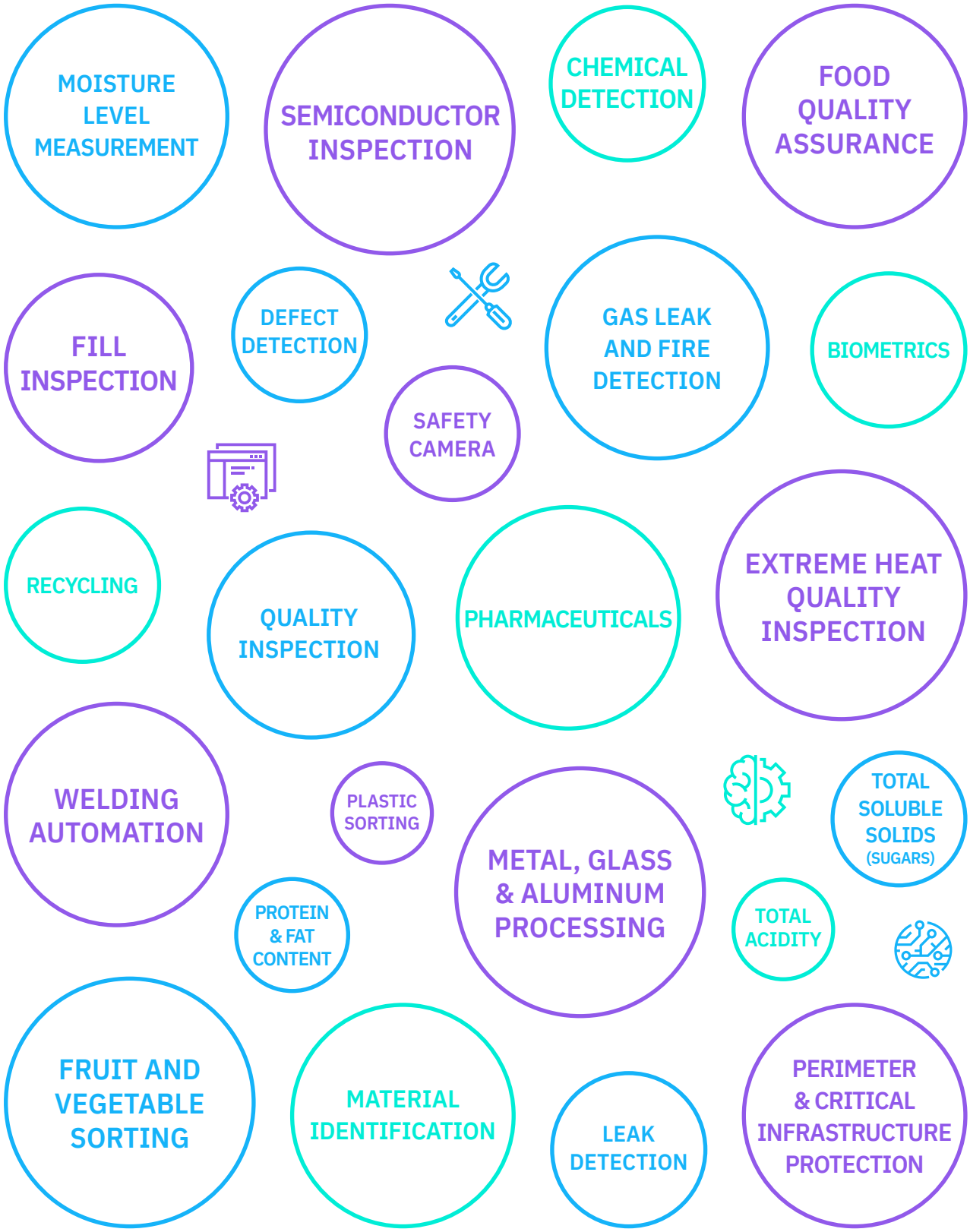
SWIR sensing systems offer advanced capabilities such as remote material classification and the ability to detect object that are indiscernible to the human eye and standard visible (VIS) cameras. They also enable the collection of rich actionable data under challenging visibility conditions like fog, smoke, or low-light.

Some industries have been harnessing the technological capabilities of SWIR for decades using Indium Gallium Arsenide (InGaAs) sensors. However, InGaAs is a compound of exotic materials, with a low production yield, and its fabrication involves multiple complex steps making the technology prohibitively expensive.

Due to their high price, large size and long lead time, InGaAs-based cameras were not applicable for mass-markets. Hence, the use of these sensors has been limited mainly to the defense, science, and aerospace sectors that can afford the high cost.

01 OPENING YOUR EYES TO SWIR FOR INDUSTRIAL USE

FIGURE 2: APPLICATIONS OF SWIR IN VARIOUS INDUSTRIES AND USE CASES



02 **WHY USE SWIR?**

I. **REMOTE MATERIAL SENSING**

Every material has a unique spectral response, or signature, defined by its chemical composition and physical characteristics, impacting how wavelengths are absorbed or reflected. By comparing the relative reflection of light between different materials in carefully chosen spectral bands, a distinction between materials is easily revealed.

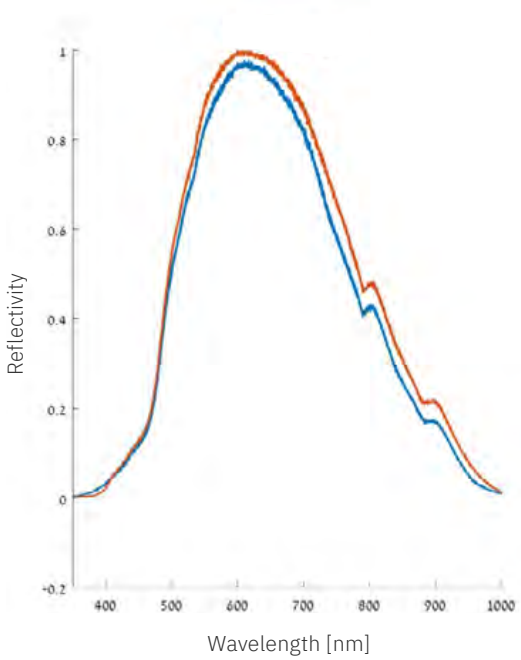
Most materials exhibit spectral differences primarily in the SWIR range. In other words, SWIR cameras can sense the differences between various materials and make them “visible”. Thus, providing actionable value for video analytics, deep learning algorithms or human operators.

In real world applications this capability is invaluable. For instance, it supports activities such as food sorting, recycling, quality and defects inspection, process and quality control, moisture measurement, leak detection, and more.

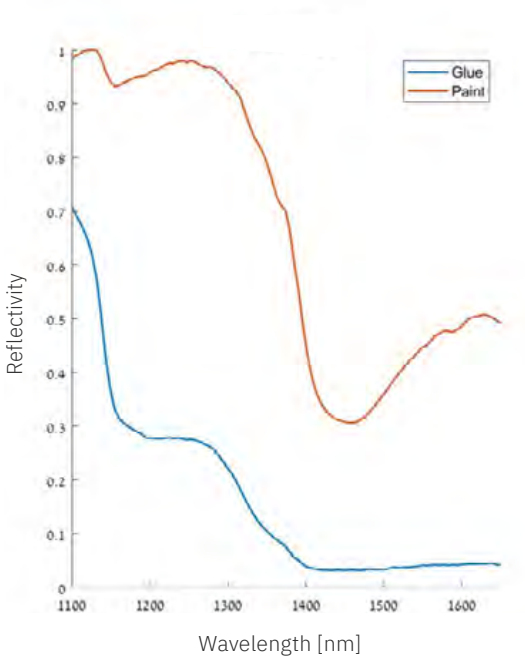
FIGURE 3: GLUE AND PAINT AS CAPTURED IN THE SWIR SPECTRUM COMPARED TO THE VIS-NIR SPECTRUM

● VISIBLE CAMERA ● SWIR CAMERA ● NIR CAMERA

VISIBLE CAMERA



SWIR RANGE



02 **WHY USE SWIR?**

II. **HIGH TEMPERATURE IMAGING**

When manufacturing processes require specific climates (such as humidity, moisture, temperature, etc.), it is vital to be able to monitor those conditions, so they are reliably maintained.

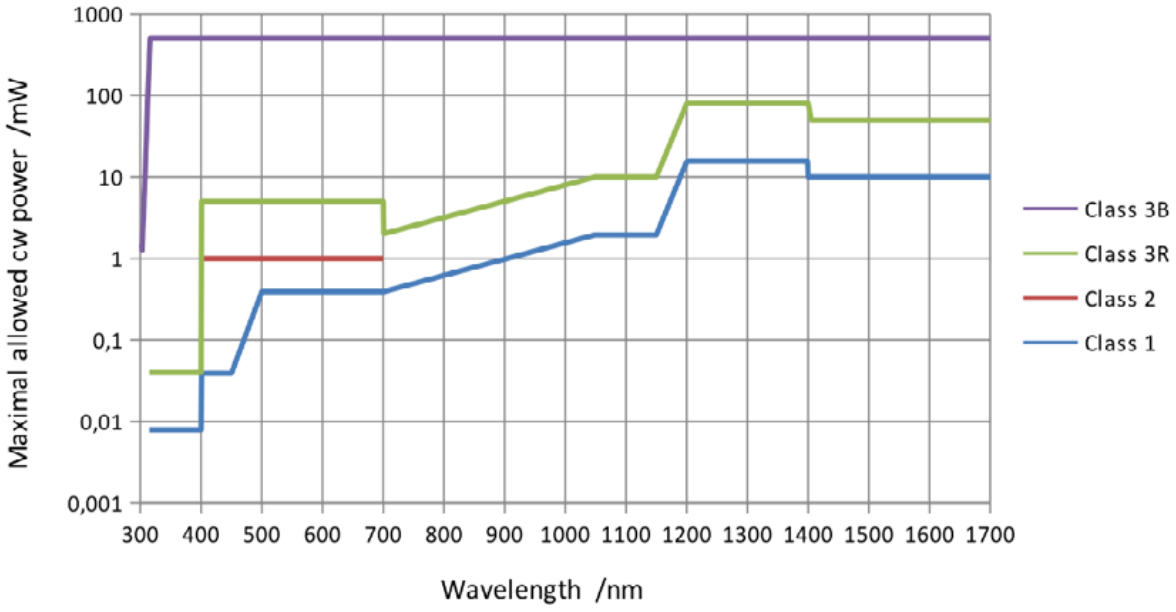
SWIR camera provide vital information for high temperature processes. For instance, in applications like metal processing, the ability to visually monitor and provide accurate temperature measurements at each stage is critical to ensuring that parts are consistently produced with the highest quality.

In addition to being able to measure temperature under extreme heat, a SWIR camera can also provide clear images as it is less affected by the heat glow of objects whereas the VIS and NIR cameras would effectively be 'blinded'. This capability enables predictive maintenance and monitoring in situations that require high temperature such as automated welding and glass fabrication.

III. **EYE SAFETY**

At most levels, illumination sources that operate in the SWIR spectrum are considered ‘eye-safe’, meaning that light at these wavelengths will not penetrate the cornea of the human eye (Class 1 laser eye-safe). SWIR illumination can be operated at optical powers three orders of magnitude higher than other wavelengths while remaining Class 1 eye-safe.

FIGURE 4: CLASS 1 EYE SAFETY ACCORDING TO THE INTERNATIONAL STANDARD IEC 60825 REGULATIONS

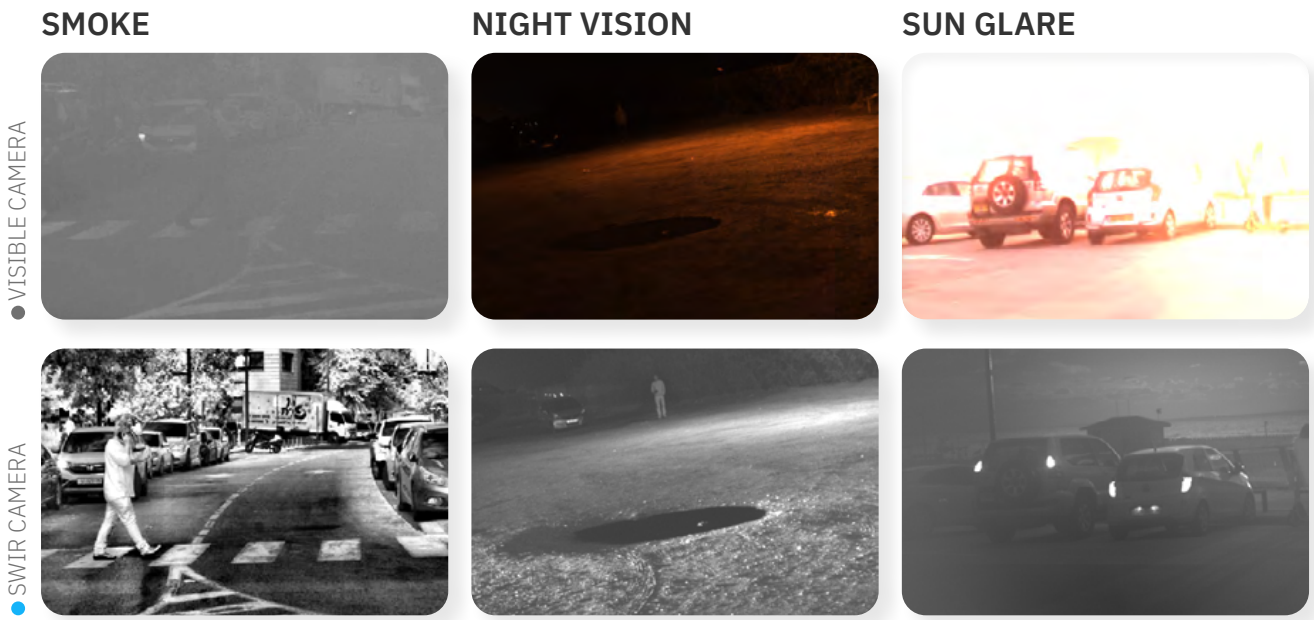


02 **WHY USE SWIR?**

IV. **SEEING CLEARLY IN ALL CONDITIONS**

Since SWIR cameras detect longer wavelengths than visible (VIS) or NIR cameras, they benefit from a lower refractive coefficient, making light less scattered. Additionally, the SWIR spectrum can operate in the solar blind region, making it resilient to ambient noise from the sun. This results in enhanced sight and an overall improvement of image quality under common low-visibility scenarios such as glare, smoke, etc. While a standard VIS camera might be blinded by these unpredictable situations, a SWIR camera offers superior vision and increases the detection range significantly.

FIGURE 5: SEEING IN ADVERSE CONDITIONS (SWIR-VIS COMPARISONS)



V. **EASE OF INTEGRATION**

Although SWIR cameras detect a different light spectrum, the image data they produce is conventional and comparable to those produced by VIS or NIR cameras. SWIR images can be analyzed using existing classic and deep learning algorithms or combined with VIS images to create richer models.
As for installation and optics, light in the SWIR spectrum can penetrate through glass and different plastics, unlike thermal imaging. This advantage means SWIR camera lenses can be manufactured using standard lens materials and can be mounted behind glass, just like VIS or NIR cameras.

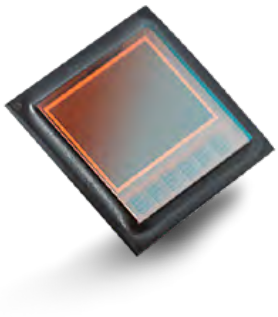
FIGURE 6: LEVERAGING EXISTING AI ALGORITHMS WITH SWIR IMAGING - OBJECT DETECTION THROUGH FOG, USING GLASS LENSES

VISIBLE CAMERA

SWIR CAMERA

03 THE TRIEYE ADVANTAGE: CMOS-BASED SWIR SENSING SOLUTION

While existing SWIR solutions rely on expensive InGaAs fabrication processes, TriEye provides SWIR sensing capabilities that are suited to serve mass-market applications. Based on advanced nanophotonic research, TriEye's technological breakthrough enables the creation of a CMOS-based SWIR sensor. This is the **world's first** high resolution SWIR sensor designed from scratch to scale, which is a significant breakthrough in sensor technology.



I. HD IMAGING WITH A WIDE SPECTRAL RANGE

TriEye's innovative sensor produces high resolution images. The rich HD image data is crucial for advanced recognition and identification and can cover a larger field of view. Moreover, the sensor's wide spectral sensitivity of 0.4-1.6µm allows for detection of a wide range of materials.

II. THE COST DIFFERENTIAL

Until now, most of the commercially available SWIR sensors were based on InGaAs technology which has a very high cost, in the range of tens of thousands of US dollars. The high cost is determined from factors such as; limited wafer size, the need for die-to-die bonding, low production yield, compound scarcity, and more. TriEye's patented technology is based on a CMOS manufacturing process which overcomes these obstacles and significantly reduces manufacturing costs by an order of magnitude, compared to the current InGaAs-based expenditure rate.

III. SCALABILITY

TriEye has forged a strong strategic partnership with a global CMOS foundry to fabricate TriEye's sensor according to a unique patented design. This enables mass production at the scale requirements of different industrial applications.

IV. RELIABILITY

TriEye utilizes a reliable process and existing fabrication tools that have supported the fabrication of other CMOS-based sensors in the past, leading to a very reliable product. The manufacturing process has proven to deliver stable and uniform sensor performance invariably. Therefore, TriEye's CMOS-based SWIR sensor unlocks transformative sight technology that is reliable and robust.

V. SIZE, WEIGHT, AND POWER (SWAP)

TriEye's Raven sensor has a small form factor, a low power consumption, and can be easily integrated with existing machine and camera designs. This enables compliance with the requirements of diverse machine vision systems for a variety of applications.

VI. EASE OF INTERNATIONAL EXPORT

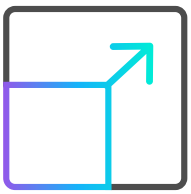
InGaAs-based SWIR sensors are highly restricted by export regulations due to their technical characteristics and their use in defense and aerospace applications. TriEye's SWIR sensor is CMOS-based designed for commercial applications, and provides the freedom to operate around the globe without regulatory limitations.

03 THE TRIEYE ADVANTAGE: CMOS-BASED SWIR SENSING SOLUTION

THE BENEFITS OF CMOS-BASED SWIR CAMERAS

COST DIFFERENTIAL

Reduce the expenditure by >1000x using a deep-tech approach, overcoming the obstacle of InGaAs-based SWIR sensors



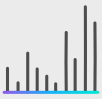
SCALABILITY

Partnering with a global leading CMOS foundry which fabricates TriEye's sensor based on the company's unique design

ALWAYS HD

Incomparable efficacy under low-visibility conditions that allows simple and flexible integration, consistent with the product design

SWIR CAPABILITIES



REMOTE MATERIAL SENSING

IMAGING IN ADVERSE WEATHER

IMAGING IN NIGHT CONDITIONS

MOUNTING BEHIND GLASS

EXISTING AI ALGORITHMS

EYE-SAFE

CMOS-BASED SENSOR

1000X LOWER PRICE

LOW POWER CONSUMPTION

HIGH RESOLUTION

RELIABILITY

SMALL FORM FACTOR

LIGHT WEIGHT

04 APPLICATIONS SPOTLIGHT

I. MATERIAL IDENTIFICATION

Hyperspectral and multispectral imaging enables both qualitative and quantitative characterization and analysis of objects and materials based on their spectral properties. These methods use reflected, transferred, or emitted light from the target at different wavelengths to decipher the object's spectral "fingerprint".

Analyzing the spectral fingerprint of a target object can reveal information that leads to its identification and classification, as well as differentiation between its various components. This process is widely used in mineral exploration, agriculture, plastic sorting, quality assurance, pharmaceuticals and many other use cases and industries.

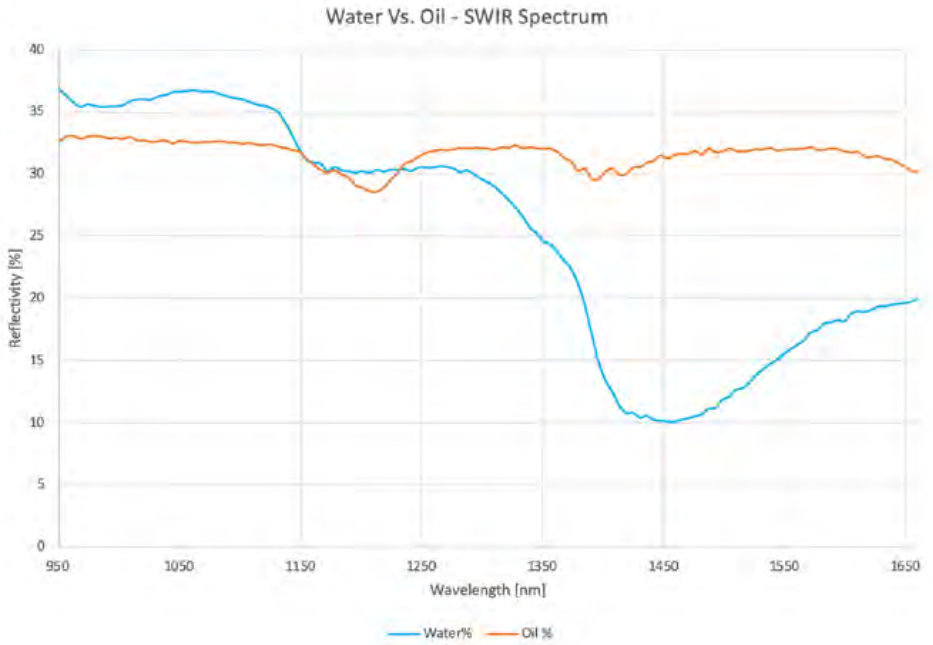
Challenge: Many materials can be detected by hyperspectral or multispectral cameras which operate in the SWIR spectrum. However, due to the high price of InGaAs-based SWIR sensors, the use of hyperspectral and multispectral cameras is limited mainly to research labs and not widespread or integrated into industrial production lines.

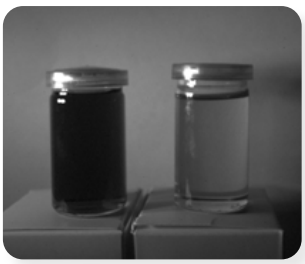
Solution: TriEye's SWIR sensor, the Raven, has a significantly lower cost and high production scalability that enables the deployment of hyperspectral cameras within other domains and industries,meaning this technology is no longer restricted to specialized labs.

Given that this sensor provides high resolution and has a wide spectral sensitivity (0.4-1.6µm), using hyperspectral cameras based on TriEye's technology will provide accurate real time analysis of the type and purity of tested materials.

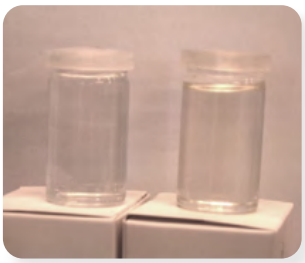
In addition, the sensor's small form factor allows for easy integration into a variety of products, even mobile or handheld devices. This significantly reduces the amount of samples sent to the lab, a process that can take several days and is extremely expensive and error prone.

FIGURE 7: THE DISTINCT SPECTRAL REFLECTANCE FINGERPRINTS OF OIL AND WATER ALLOW PRECISE DETECTION AND DIFFERENTIATION





SWIR CAMERA



VISIBLE CAMERA

04 APPLICATIONS SPOTLIGHT

I I. FOOD SORTING AND CONTAMINANT DETECTION

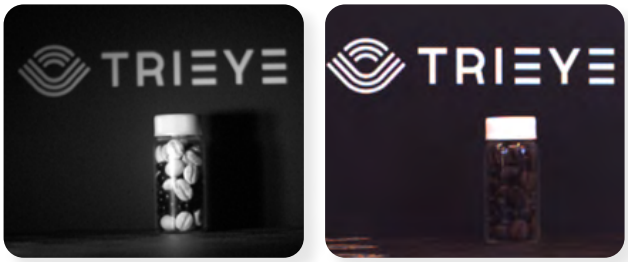
The food industry must follow strict quality control guidelines to uphold high standards and government regulations. Imaging is often used to recognize unwanted foreign objects, contaminants, or material impurities (like stones, leaves, shells, or insects) effectively and automatically. The esthetics of a food product also plays an important role in its ability to be sold. Visually detecting imperfections or expiring items can quickly help determine whether to direct produce to retail or to food processing industries.

Challenge: With standard cameras, differentiating between a product and unwanted impurities is very difficult. SWIR cameras, however, can easily visualize the difference between such materials, but their traditionally high cost and limited availability makes it impossible to deploy them in production lines. Samples must be shipped to special labs that have expensive measurement tools, making the whole process slow, expensive, and prone to errors since not every item is inspected.

Solution: TriEye's CMOS-based SWIR sensor makes real-time monitoring and accurate quality control possible, at a price point that is relevant for food and agriculture industries. On top of ensuring that quality food reaches the public's plate, this will increase manufacturer profit margins with minimal investment and overhead costs.

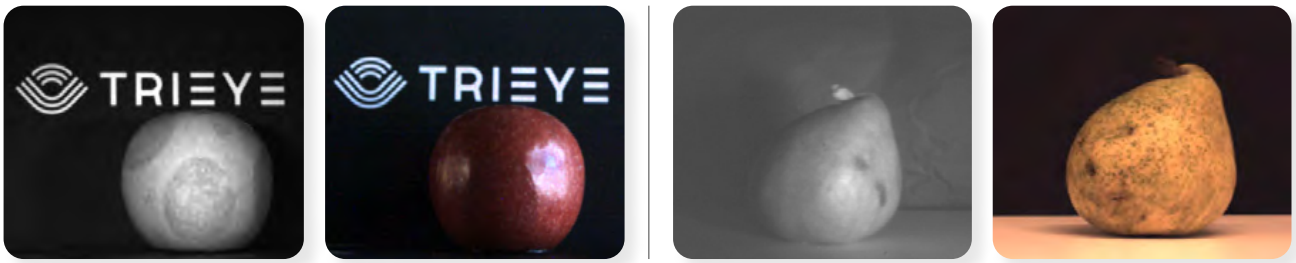
FIGURE 8: POSSIBLE USE CASES OF GOOD SORTING AND CONTAMINANT DETECTION IN THE VIS VS. THE SWIR SPECTRUM

A. CONTAMINATION DETECTION - COFFEE BEANS VS PLASTIC BEADS



● SWIR CAMERA ● VISIBLE CAMERA

B. PRODUCE DAMAGES



● SWIR CAMERA ● VISIBLE CAMERA ● SWIR CAMERA ● VISIBLE CAMERA

C. IDENTIFICATION OF SUGAR & SALT LEVELS IN FOOD: SALT VS SUGAR DIFFERENTIATION

● SWIR CAMERA ● VISIBLE CAMERA

04 APPLICATIONS SPOTLIGHT

III. REMOTE MOISTURE SENSING AND LEAK DETECTION

Water has a distinct absorption peak in the SWIR spectrum, meaning SWIR has the capability to identify the amount of water in substances including; soil, concrete, textile, plants, coffee beans, and more.

The US, German, and Indian governments have already set regulations that mandate the use of moisture sensors in various industries. For example, the Food Safety and Standards Authority of India (FSSAI) requires the use of moisture sensors in the food & beverage industry to prevent spoilage and contamination.

SWIR cameras can also detect water presence in different environments saving millions of dollars in water wastage and maintenance. For example, being able to detect a leaking pipe in water treatment factories or underground leaks in vast municipal areas.

Challenge: Most standard moisture sensors currently on the market are limited because they require direct contact with the surface they are examining to function properly. This makes the integration of such sensors complicated and expensive.

While InGaAs-based SWIR sensors enable contactless moisture measurement and leak detection, they are extremely expensive. Development of sensors that are both contactless and cost-effective will unlock the immense growth potential previously unaccessible in numerous markets.

Solution: TriEye's CMOS-based HD SWIR sensor can remotely measure the moisture level of different objects and its low cost allows for wide cross-market adoption. The sensor's high resolution enables the examination of large areas with just one installation and its small size and low power requirements make integrations easy.

FIGURE 9: THE SPECTRAL REFLECTANCE OF WATER

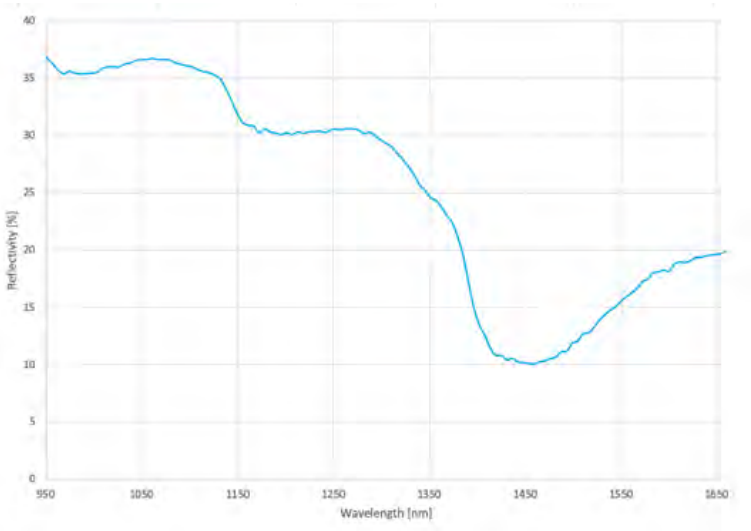


FIGURE 10: LEAK DETECTION AS CAPTURED IN THE VIS VS THE SWIR SPECTRUM

● VISIBLE CAMERA

● SWIR CAMERA

04 **APPLICATIONS SPOTLIGHT**

IV. **RECYCLING**

Raw materials in our daily “garbage” can be repurposed to create new products through the process of recycling. Thus, the identification of different materials, such as plastics or metals, is a crucial step in the recycling process.

Challenge: In many cases it is impossible to differentiate between raw materials because they are not discernible with standard cameras. Although current SWIR cameras could solve this, their high cost and limited availability prohibits their integration in industries that operate with very low profit margins, such as recycling.

Very few recycling facilities pay the high cost to automate their sorting process using SWIR sensors. In most facilities around the world this process is done manually, which is expensive and prone to human error, not to mention dangerous.

Solution: The TriEye SWIR camera offers automatic and accurate identification of a diverse range of mixed materials. Its integration into the recycling process can decrease sorting errors and increase the profitability of recycling businesses. Resulting in the creation of higher quality recycled materials and a cleaner planet for us all.

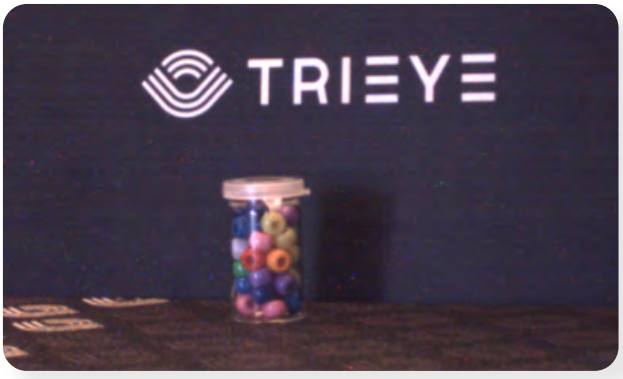
FIGURE 11: DIFFERENTIATION OF MATERIALS BECOMES EFFORTLESS WHEN VIEWED IN THE SWIR SPECTRUM - FROM LEFT TO RIGHT: PLASTIC, SILICONE, STONE, WOOD, AND GLASS.

● SWIR CAMERA

● VISIBLE CAMERA

FIGURE 12: IDENTIFICATION OF SIMILAR MATERIALS, EVEN IN DIFFERENT COLORS, BECOMES EFFORTLESS WHEN VIEWED IN THE SWIR SPECTRUM

● SWIR CAMERA



● VISIBLE CAMERA

04 APPLICATIONS SPOTLIGHT

V. QUALITY AND DEFECTS INSPECTION

Visual defect inspection is a crucial and significant part of quality assurance. Machine vision systems automate the inspection task and help identify and measure visible defects. Using this, manufacturers are able to objectively monitor product quality parameters in real-time making defects both recognizable and actionable. This ensures consistent product quality and mitigates the possibility of a product recall.

Challenge: Although inspection systems based on VIS cameras are already widespread, there are many defects which these cameras, and the naked eye, cannot detect. For example, soldering point drift on a PCB may be too subtle to be noticed, glue residue on products may be transparent, and uneven bottle filling might not be noticeable.

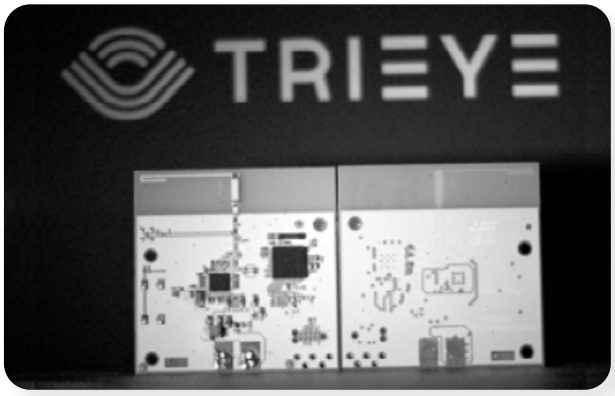
Leveraging the SWIR spectrum yields the ability to sense materials rather than colors, turning once hard to recognize transitions into obvious high-contrast differences. Differences that would otherwise go undetected by VIS cameras, the human eye and even NIR cameras, are made clear. SWIR can also operate in previously inhibiting environments like in extreme temperatures or seeing through opaque plastic. However, until now the high cost of SWIR sensing has been a significant barrier to the adoption of this technology.

Solution: TriEye's SWIR cameras are significantly cheaper compared to other industrial SWIR sensors, unlocking the SWIR spectrum's advantages for mass market quality inspection uses.

The image below, Figure 13, compares image data from a VIS camera and a TriEye SWIR camera.

FIGURE 13: LEVERAGING SWIR IMAGING TO INSPECT THE QUALITY OF PCB BOARDS, E.G. THE SOLDERING OF DIFFERENT COMPONENTS

● VISIBLE CAMERA



● SWIR CAMERA

05 READY TO SEE IN SWIR?

TriEye's CMOS-based SWIR technology is the world's first cost-effective and scalable solution. TriEye's SWIR sensor is becoming a key component in the future of industrial machine vision applications. From identifying invisible threats and real-time malfunctions to the sorting of food and materials. Its unique innovative technology can supercharge the capabilities and efficacy of in-place machine vision systems.

TRIEYE OVI DEVELOPMENT KIT

The Ovi development kit is designed to quickly introduce developers to the seamless use of TriEye's Raven sensor. The Ovi is a highly customizable tool that requires minimal setup and allows developers to quickly ramp up and tap into the benefits of the SWIR spectrum, accelerating the development cycle toward commercialization.

SPECIFICATIONS

HW

Modular Stacked Board Devkit
- Sensor Board
- Connectivity Board
- Frame Grabber Board
- ISP Board (optional)
- Serializer/De-Serializer board (optional)

USB3 and External Sync cables
Serial cable (optional)
Size 62 x 62 x 55 mm
C-mount

OPTICS (OPTIONAL)

Several options available (contact sales)

ILLUMINATION (OPTIONAL)

Several options available (contact sales)

SW

Viewer-Recorder-Controller (VRC) tool
DevWareX Raven Plugin
TriEye API (TEA)
ISP SW

OS SUPPORTED

Windows
Linux

TRIEYE RAVEN SENSOR

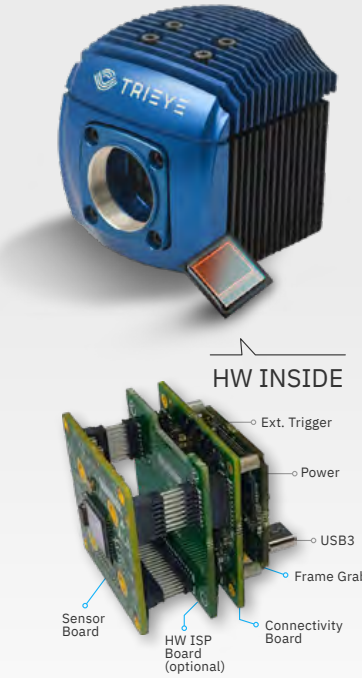
Sensor Spectrum: 0.4 – 1.6µm
Resolution: 1284 x 960
Frame Rate: Up to 120 fps
Shutter: Global/Rolling
Output Format: 8/10/12-bit Raw

SENSOR CONTROL

Exposure control
FPS control
ROI support
Binning support

ADDITIONAL SW FEATURES

Image preview
Sync with another camera
Illumination control
Save images as BMP/Tiff
Save videos as AVI/MP4
Internal registers access
Image analysis capabilities
Diagnostic information analysis



To learn more contact us at sales@trieye.tech or visit www.trieye.tech

ABOUT TRIEYE

TriEye is a fabless semiconductor company developing a unique, mass-market, and affordable SWIR sensing technology based on academic research in nanophotonics. TriEye's team are experts in SWIR technology specializing in device physics, process design, electro-optics, and deep learning.

SEEING BEYOND THE VISIBLE

TRIEYE

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