TRIEYE

AUTOMOTIVE

WHITEPAPER

HOW SWIR IS SOLVING THE LOW VISIBILITY CHALLENGE FOR ADAS AND AV

TABLE OF CONTENTS

01 **SETTING THE STAGE**
ADAS SYSTEMS AND ROAD VISIBILITY

While autonomous vehicles are still far from being available to the average driver, most cars on the market offer Advanced Driver-Assistance Systems (ADAS), semi-autonomous features that significantly enhance vehicle reliability and safety.

Most collisions (94%) occur as a result of human error, therefore ADAS applications have been developed to increase driver safety and decrease the risk of an accident. ADAS features such as lane marking detection, pedestrian warning, and emergency braking were all developed to enable drivers to make better decisions. ADAS applications have proven their value and managed to reduce the number of road fatalities.

However, as valuable as ADAS technology has proven to be at improving driver's safety, there is still a long way to go. ADAS technology urgently needs better sensors which can assist drivers in the identification of visible and invisible hazards, enabling those advanced systems to better "see" the world in front of and around them.

Today, driver-assistance systems are not functional in low light and adverse weather conditions. In that matter, a recent AAA study revealed that none of the systems were able to detect an adult pedestrian crossing in front of the vehicle at night, when testing automated emergency brake systems with pedestrian detection. **The low visibility challenge must be solved because most severe road accidents happen in these conditions.** In fact, even though the number of miles driven at night are substantially lower than during the daytime, more than half of all fatalities occur at night. For example, in the United States almost half (49%) of road fatalities occur during night time, making nocturnal driving twice as dangerous as daytime driving.

The fact that ADAS technology on the market today can reduce the likelihood and severity of an accident is undisputed, but until now, it has not been able to offer a consistent solution when it is most needed.

FIGURE 1: SENSOR FUSION UNDER A CLEAR BLUE SKY
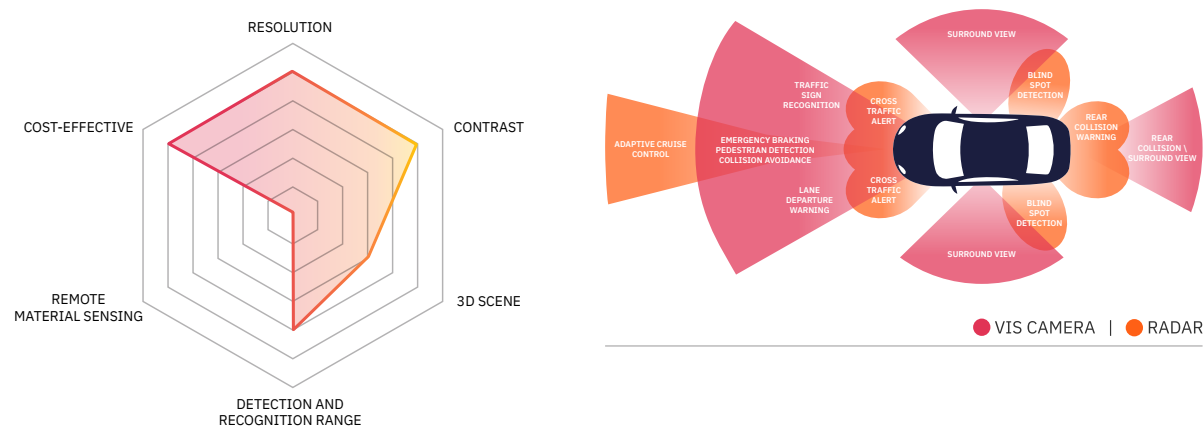
02 PITFALLS AND SHORTCOMINGS IN IMPROVING DRIVER SAFETY

Ⅰ SENSOR FUSION BLIND SPOTS

Sensor Fusion is the synergy of information from a variety of sensors. Most vehicles manufactured these days have two primary types of sensors combined for use in ADAS applications: Standard Visible (VIS) Cameras and radar. Additionally, there is the LiDAR sensor, which is considered primarily applicable for higher automation applications.

VIS camera sensors are used for detecting lane markings, signs, vehicles, and pedestrians where as radar sensors are used to measure the distance to an object and its speed. LiDAR sensors measure the distance to objects in a higher resolution than radar, but are extremely expensive and difficult to scale and integrate.

In mass market applications, **pricing is a crucial factor for decision-making** . Within the automotive industry this point of consideration is even more crucial; ADAS components need to be cost-effective in order to be considered by Original Equipment Manufacturers (OEMs). In some cases, decision makers are forced to choose pricing over the integration of cutting-edge technologies. This consideration intensifies the industry's need for a cost-effective, reliable and safe system, which can support HD vision in all driving conditions.
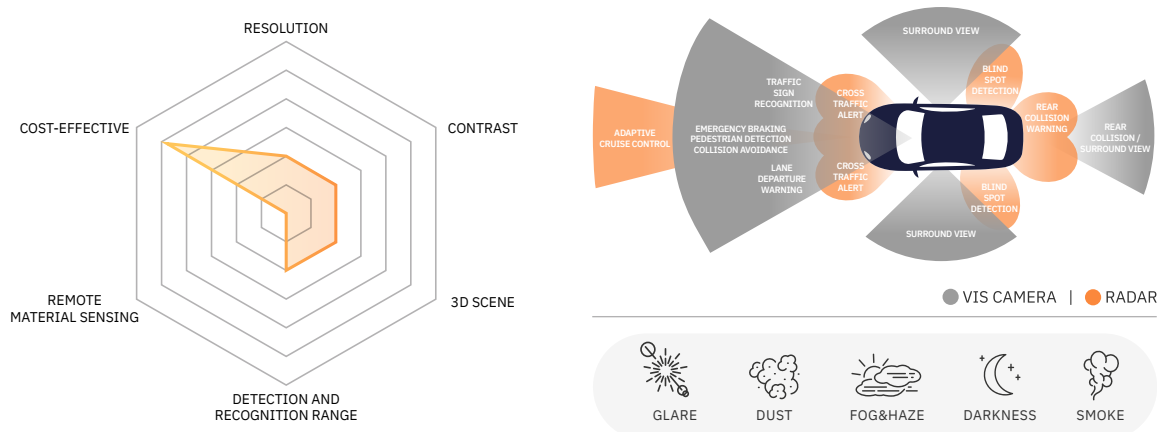
Ⅱ ADVERSE WEATHER AND LOW LIGHT CONDITIONS

A major hurdle in the creation of a truly secure ADAS solution has been the creation of a sensor that can see through fog, haze and dust, as well as in the dark. This is an urgent concern, considering that 75% of pedestrian fatalities occur at night and the technology currently on the market has proven that it is not up to the task of providing a clear view of the road ahead in low visibility driving conditions.

On a clear day, existing products can offer the required resolution, contrast, detection and recognition range. However, they fail to compensate for common instances of diminished visibility. This is the most critical challenge preventing a consistent and effective solution. Even when combining existing sensors into one system, they are still unable to operate under all weather and lighting conditions.

As a result, the driver assistance systems simply do not have the critical information about their immediate environment that they require to make smart and safe decisions. The danger this presents cannot be underestimated, particularly in light of the fact that **most severe road accidents happen in low visibility conditions.**

FIGURE 2: SENSOR FUSION FAILS UNDER COMMON LOW VISIBILITY CONDITIONS

# 02 **PITFALLS AND SHORTCOMINGS IN IMPROVING DRIVER SAFETY**

III. **DETECTABLE AND UNDETECTABLE HAZARDS**

In addition to poor performance in adverse weather and low light conditions, the existing sensor fusion solution has shortfalls in accurate object detection. Even under optimal visibility conditions, its hazard detection, of pedestrians wearing dark clothes or dark-furred animals crossing the road, is extremely deficient and poses a serious danger.

Furthermore, while standard VIS cameras can differentiate between a person and an animal, they cannot always differentiate between a real person and a picture of a person. Putting object detection at risk of "phantom" objects and other attacks. Being able to distinguish between visible hazards on the road like debris, pedestrians, and animals darting into the road, as well as hazards that the human eye cannot detect such as black ice, are vital to saving lives.

Currently, invisible hazards such as black ice or oil slicks on asphalt are impossible to detect from a safe distance. In adverse weather and low light conditions it can be an even greater challenge to identify these invisible dangers on the road that threaten vehicle safety.

FIGURE 3: SENSOR FUSION LIMITED DETECTION CAPABILITIES OF UNSEEN HAZARDS
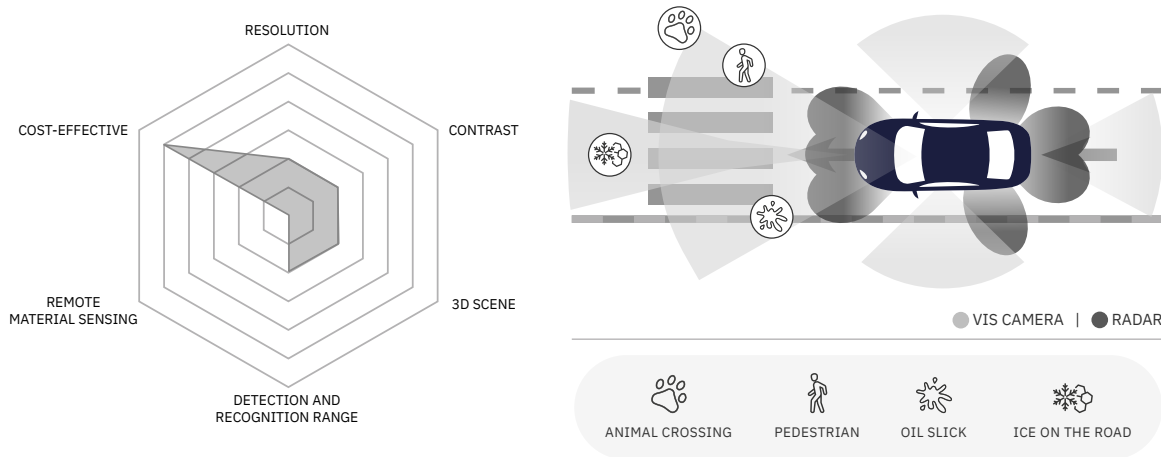
03 WHAT IS THE LOW VISIBILITY CHALLENGE?

Addressing the low visibility challenge is of the utmost importance. According to the Federal Highway Administration (FHWA), over 5 million crashes take place annually, 22% of which are weather-related. The ability to see, while driving in snow, rain, fog and sandstorms would cut the number of accidents and significantly reduce the amount of severe injuries and fatalities.
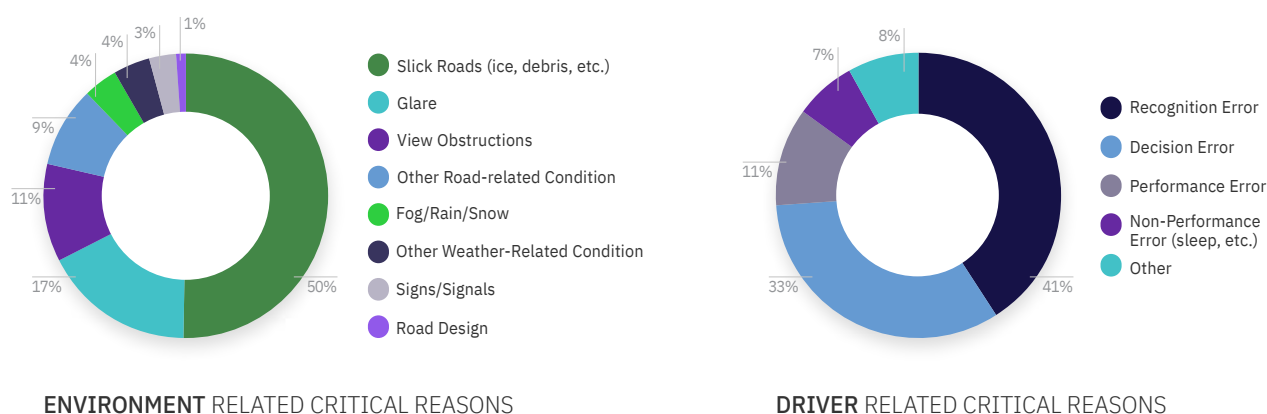
Night is also a critical factor in vehicle safety, as it is when pedestrians, drivers and passengers are at their most vulnerable. A disproportionate number of fatal road injuries occur after dark; Accident statistics across the United States reinforce the urgency of finding a solution to the limitations ADAS technologies face when used in nocturnal driving. According to NHTSA, the passenger vehicle occupant fatality rate at nighttime is about three times higher than the daytime rate. Nationwide, almost half (49%) of road fatalities occur during night time.

Unfortunately, the sensor fusion systems available on the market do not work at the times they are most needed - when visibility is compromised. So, it is critical for ADAS technology to evolve to a point where driving in bad weather and lighting conditions are no longer an activity which risks lives.

To this end, TriEye has developed the Raven CMOS-based SWIR solution, which takes a significant step forward in improving visibility under challenging driving conditions.

FIGURE 4: CRITICAL REASONS FOR CRASHES INVESTIGATED IN THE NATIONAL MOTOR VEHICLE CRASH CAUSATION SURVEY CONDUCTED BY NHTSA
Source: crashstats.nhtsa.dot.gov

Environment Related Critical Reasons:
- 50% Slick Roads (ice, debris, etc.)
- 17% Glare
- 11% View Obstructions
- 9% Other Road-related Condition
- 4% Fog/Rain/Snow
- 4% Other Weather-Related Condition
- 3% Signs/Signals
- 1% Road Design

ENVIRONMENT RELATED CRITICAL REASONS

Driver Related Critical Reasons:
- 41% Recognition Error
- 33% Decision Error
- 11% Performance Error
- 7% Non-Performance Error (sleep, etc.)
- 8% Other

DRIVER RELATED CRITICAL REASONS

04 **SOLVING THE PROBLEM WITH SWIR**

I **WHAT IS THE SWIR SPECTRUM?**

Short-Wave Infrared (SWIR), refers to a specific wavelength range from 1000nm to 1600nm. For reference, standard cameras usually operate between 0.4-0.75μm spectrum. SWIR allows for a number of applications to be performed that weren't previously possible using visible light and with great results. In contrast to cameras on the visible spectrum, a SWIR camera has a lower refractive coefficient, meaning that it is significantly less scattered and can perceive what standard cameras in the visible spectrum are not able to see. Thus, "Seeing Beyond the Visible".

Reliable and consistent, the SWIR camera can offer superior sight, functionality, and operability under all weather and lighting conditions. In the automotive market, it has the potential to enhance human driver capabilities and assist in the detection of previously invisible hazards on the road, a sensing capability that was not available at a low cost until now.

Another significant advantage of SWIR is that it is a useful tool for remote material sensing. By comparing the relative intensities of carefully chosen spectral bands, the differences between spectral signatures are revealed. This allows for differentiation between target materials such as ice or water covered regions on an asphalt surface (referenced in Section E).

VISIBLE	NIR	SWIR
0.4 [μm]	0.75 [μm] 1.0 [μm]	1.6 [μm]
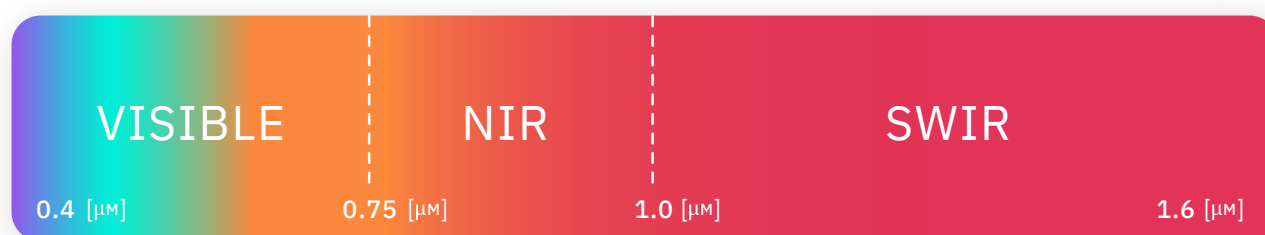
II. **SWIR BENEFITS**

A. **SENSORS IN FOCUS - SWIR VS. FOG**

Fog is caused by supersaturation of the air close to the earth's surface, which creates suspended droplets of moisture. It can be incredibly hazardous, reducing visibility to just a few meters. While a standard VIS camera image might be completely obscured by fog because it creates a white "screen" that blinds it, a SWIR camera can see through fog because of its high penetration coefficient.
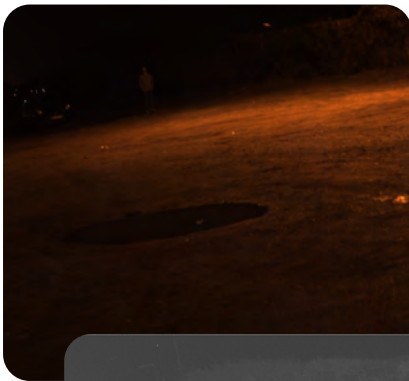
SWIR cameras are able to see for longer ranges than visible cameras because light is less scattered in the SWIR wavelength, increasing detection range significantly.

● VISIBLE CAMERA

● SWIR CAMERA

● VISIBLE CAMERA

B. **SENSORS IN FOCUS - SWIR VS. NIGHT TIME**

Driving at night presents a unique set of dangers, being that majority of accidents occur after dark. At night, a VIS camera, just like the human driver, has difficulty recognizing objects, people, animals, and other vehicles, due to lack of photons in low light. This drastically limits the car's vision to the narrow area that is illuminated by its headlights.

However, a SWIR camera can achieve significant visibility distance in the dark, offering effective night vision capabilities and greatly lowering the risk of collision.

● SWIR CAMERA

C. **SENSORS IN FOCUS - SWIR VS. DUST**

Dust and sandstorms are common phenomena in arid and semi-arid regions. These unpredictable conditions present a particularly dangerous threat to drivers. Sandstorms can cause thick clouds of dust that obscure the road and can lead to zero visibility conditions. A SWIR camera is able to offer better visibility in such scenarios because the light is less scattered in the SWIR spectrum compared to the visible spectrum.

D. **HAZARD DETECTION - PEDESTRIANS AND ANIMALS ON THE ROAD**

Arguably, one of the most unpredictable road hazards is unexpected animals or pedestrians in the road. This is especially true in low visibility conditions where AI algorithms might not be able to detect and recognize. The challenge becomes even bigger if the person is wearing dark clothing or a dark-furred animal is present. The enhanced vision capabilities of the SWIR camera substantially improve the detection algorithm performance, therefore reducing the risk of a collision in such a scenario and increasing safety of all road users.

In the image below (Figure 5), the VIS camera shows pedestrians wearing dark clothing, which make them hard to detect even in broad daylight. Yet, their clothing appears much lighter with the SWIR camera. The reason being that SWIR detects the material of the object, not its color. So cotton material will appear as bright white in the SWIR spectrum, making it a beneficial tool for hazard detection.

04 **SOLVING THE PROBLEM WITH SWIR**

● VISIBLE CAMERA - OBJECTS UNDETECTED   ● SWIR CAMERA - OBJECTS DETECTED

As seen in Figure 5, a dark-furred animal is even harder to see with a VIS camera. The animal's dark appearance is due to the high melanin content of their fur which absorbs the light instead of reflecting it to the camera. As the wavelength of the light increases from the VIS to the SWIR spectrum, the absorption decreases by more than an order of magnitude. A significant challenge, taking into account that more than 1.3 million deer-related accidents occur every year in the United States alone.

FIGURE 6: MELANIN ABSORPTION
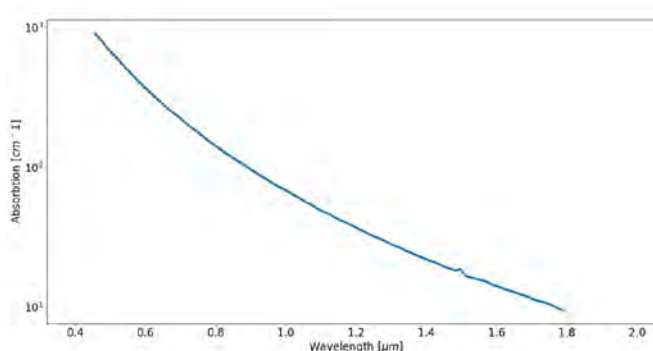
SWIR sensors can enhance the ability of ADAS systems to recognize animals and pedestrians at all times, significantly improving road safety and dramatically reducing these collision statistics.

E. **REMOTE MATERIAL SENSING**

Identification and detection are major problems for VIS cameras; a dark spot on the road could be a shadow, a puddle, or a pothole. Car reflections off buildings could be identified as an oncoming vehicle and confuse the sensor. SWIR technology offers superior and more accurate detection because SWIR cameras can detect materials and are not confused by colors.

Every material has a unique spectral response defined by its chemical and physical characteristics that can be detected by comparing the relative intensities of carefully chosen spectral bands. This is known as remote material sensing.

There are hazards which are invisible to both the driver and ADAS sensor fusion solutions, where the ADAS system isn't able to detect or alert the driver of the hazard until its too late to prevent an accident. - e.g. when the vehicle is already slipping on black-ice. This is a major challenge for self-driving cars and human drivers alike, exposing them to significant risks. SWIR cameras allow for the detection of unseen or obscured hazards at longer ranges.

In real world scenarios this capability is invaluable since it enables differentiation between target materials such as ice or water covered regions on an asphalt surface. As shown in Figure 7, a SWIR camera allows drivers to easily distinguish the black ice on the asphalt, with the same ease as they would differentiate between red and blue.

FIGURE 7: ASPHALT THROUGH WATER AND ICE
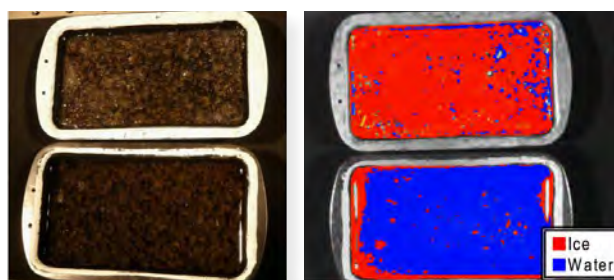
● VISIBLE CAMERA   ● SWIR CAMERA
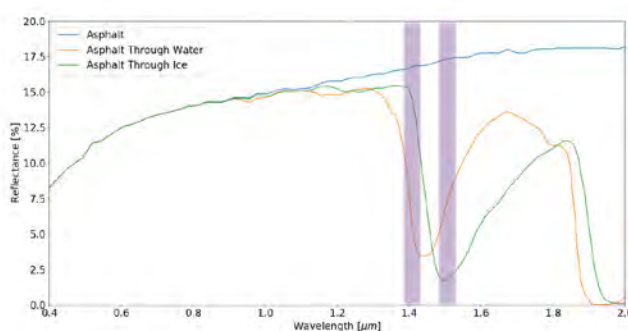
Source: Shigeki Nakauchi, Ken Nishino, and Takuya Yamashita, Toyohashi University of Technology, Japan

F. **SEEING THROUGH GLASS**

SWIR technology is able to see through glass. Unlike LiDAR and radar sensors that require visible exterior mounting on the car roof or bumper, SWIR cameras can be mounted behind the windshield or in the car headlight. This is the preferred location for car manufacturers since it allows for maximum image clarity and doesn't require exterior design modifications.

Moreover, windshield positioning offers an optimal view of the road and it means that the manufacturer does not need to be concerned with implementing a cleaning system.

G. **REUSING EXISTING AI ALGORITHMS**

SWIR image data can be processed with the same algorithms that were developed for VIS cameras. Using existing deep learning algorithms simplifies the development process, saving significant time and resources, as the algorithms do not need to be developed from scratch which requires driving millions of miles physically and trillions of miles virtually.

FIGURE 8: OBJECT RECOGNITION
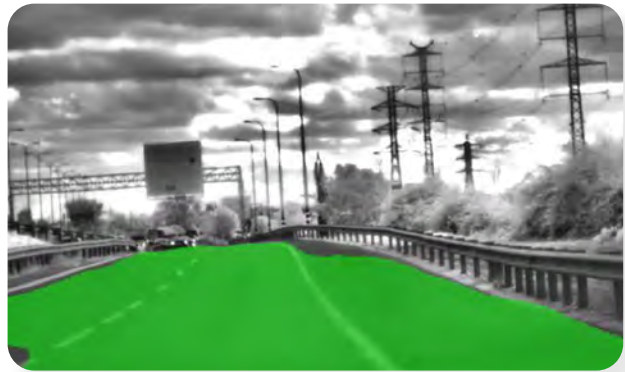

●VISIBLE CAMERA   ●SWIR CAMERA

For example, for SWIR Object Recognition capabilities, open source visible algorithms are utilized, with almost 4,000 frames able to be retooled as SWIR camera data (Yolo by TensorFlow) as shown in Figure 8.

FIGURE 9: SEMANTIC ROAD SEGMENTATION

●VISIBLE CAMERA   ●SWIR CAMERA

Another example is that of Semantic Road Segmentation based Fully Convolutional Network (FCN-8 Architecture developed at Berkeley). It uses VGG16 pre-trained on ImageNet.

H. **EASE OF INTEGRATION**

SWIR cameras collect and produce regular image data, similar to the data produced by a standard VIS camera. This simple output type allows engineers to integrate it easily with existing systems that are currently being used by car manufacturers and process the image in similar methods.

I. **EYE SAFETY**

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
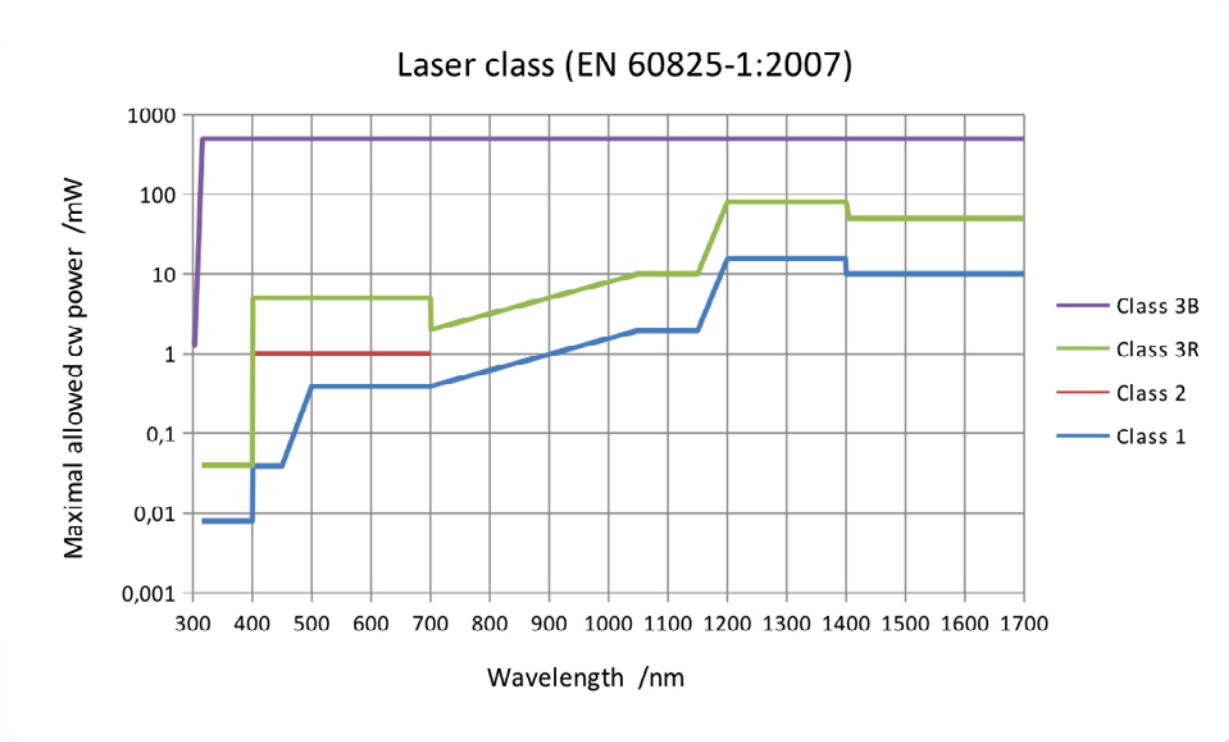
III. **A DEEP DIVE INTO THE SENSOR SOLUTIONS: INGAAS-BASED VS CMOS-BASED SWIR CAMERAS**

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

The industries using this technology include defense, science, and aerospace, sectors that can afford the high cost. Due to its high price and long lead time, InGaAs-based cameras are not suitable for mass-market applications. Additionally, the cameras can be large and cumbersome which is also an entry barrier to mass-market adoption.

Conversely, CMOS-based cameras can be manufactured with far greater ease and at a cost one thousand times lower than that of InGaAs-based cameras. They are more reliable, scalable, energy efficient, provide much higher resolution and can be miniaturized and integrated into a mobile phone camera. Standard CMOS-based sensors today are not able to sense the SWIR spectrum because their sensitivity is extremely low above 1um.

Based on advanced nanophotonics research, TriEye's cutting edge technology enables SWIR sensing on a CMOS-based sensor for mass-production. This unique combination enables vision in adverse weather and nighttime conditions, and allows for better visualization of potential hazards on the road; a significant technological breakthrough in the automotive sensor industry.

05 TRIEYE RAVEN CMOS BASED SWIR SENSOR

I. HD IMAGING - SEEING CLEARLY IN ALL CONDITIONS

TriEye's innovative camera is able to produce HD imaging of the driving scene, similar to that of a VIS camera, but with incomparable efficacy under common low-visibility conditions. Delivering high-resolution image data, it allows for safer and more reliable ADAS in low visibility conditions, better mapping of the car surroundings and a higher object detection rate. This enables ADAS applications such as emergency braking systems and pedestrian warning tools to operate consistently, offering peak visibility day or night and in the most extreme weather.

II. THE COST DIFFERENTIAL

Until now, available SWIR technology had a significantly high cost, tens of thousands of USD, due to a lack of compatibility with CMOS-based sensors, limited wafer size, the need for die to die bonding, low yield, and more.

TriEye's patent-pending technology, which includes compatibility with a CMOS-based sensor, is able to overcome these obstacles and eliminate the exorbitant manufacturing costs of using InGaAs, a material characterized by its scarcity, low production yield, and a complex and expensive manufacturing process. This has enabled TriEye to reduce expenditure a thousand times the current industry rate.

III. SCALABILITY

TriEye is partnering with a global leading CMOS foundry which fabricates TriEye's sensor based on the company's unique design. This partnership allows for mass production using existing tools, in order to support the automotive industry's scale requirements, while adhering to its strict regulatory and safety requirements.

IV. RELIABILITY

TriEye's sensor is highly reliable, as it uses existing fabrication tools that were already developed for CMOS-based sensors worldwide. This manufacturing process has long been proven to deliver stability and uniformity of the sensor and camera performance over time. Thus, TriEye's CMOS-based SWIR camera allows for transformative sight technology that is more reliable and robust.

V. **SMALL FORM FACTOR**

TriEye's Raven CMOS-based sensor meets the size standard required for automotive applications, allowing for a simple and flexible integration consistent with vehicle design requirements.

SENSOR MODALITIES FUNCTIONALITY

	ABILITY TO SEE IN ALL WEATHER AND LIGHTING CONDITIONS	RESOLUTION	COST	USING EXISTING AI CAPABILITIES	REMOTE MATERIAL SENSING	SIZE	MOUNTING POSITION
CAMERA	✕	✓	✓	✓	✕	✓	✓
RADAR	✓	✕	✓	—	✕	—	—
LIDAR	—	—	✕	✕	✕	✕	✕
TRIEYE	✓	✓	✓	✓	✓	✓	✓

06 **READY TO SEE IN SWIR?**

TriEye's CMOS-based Short-Wave Infrared sensor technology is the world's first cost-effective and scalable solution. This enables unprecedented machine vision capabilities suited for a wide variety of automotive use cases.

TriEye's SWIR sensor is quickly becoming a key component in highly automated driving systems. From detecting vulnerable road users at all times to identifying rather invisible hazards on the road (e.g. black ice). This innovative technology can supercharge the capabilities and efficacy of automotive vision systems.

TRIEYE OVI DEVELOPMENT KIT

SWIR cameras collect and process image data, similar to the data produced by a standard VIS camera. This type of output is easily integrated with existing systems, currently used by car manufacturers, that process the image using similar methods.

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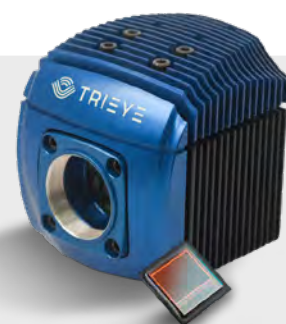Sync with another camera
Illumination control
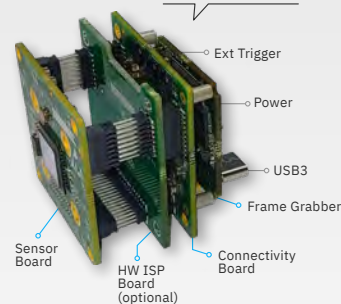Save images as BMP/Tiff
Save videos as AVI/MP4
Internal registers access
Image analysis capabilities
Diagnostic information analysis

HW INSIDE

Ext Trigger
Power
USB3
Frame Grabber
Sensor Board
HW ISP Board (optional)
Connectivity Board

07 **CONCLUSION**
THE FUTURE OF SWIR

TriEye is solving the low visibility challenge for ADAS and Autonomous Vehicles. Specifically, the company is developing a SWIR sensing solution that can deliver image data even under the most challenging visibility conditions. Furthermore, TriEye's CMOS-based SWIR sensor is the industry-first to enable remote material sensing for both visible and invisible hazards on the road, thus mitigating risks on the road and dramatically enhancing road safety.

TriEye's Raven SWIR camera enhances human driver capabilities and assists in the detection of invisible hazards on the road. The Raven's innovative technology allows life-saving ADAS applications such as emergency braking systems and pedestrian protection systems to operate in different environmental scenes and under the toughest weather and lighting conditions. This cost-effective solution delivers unprecedented vision capabilities that bring the autonomous vehicles industry closer to safer and better ADAS and AV.

TriEye enables SWIR sensing capabilities to a much broader group - it is changing the way humanity perceives the world around us by enabling another channel of crucial data, to provide a clear image where the human eye or even a standard visible camera cannot "see".

While our primary target market is the automotive industry, our technology can reshape a wide range of other sectors. The TriEye mass-market SWIR sensing solution can be utilized across numerous verticals with real-life applications; security, mobile, agriculture and even medical. Some were cost-prohibitive in the past and some will be discovered as our new sensing modality comes to life.

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

CONTACT US

info@trieye.tech
www.trieye.tech