# Review of Novel 3D Sensing Technologies for Operation in High Ambient Light Environments

JABIL | OPTICS

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## ABSTRACT

The following whitepaper discusses the common challenge of depth sensor operation in high ambient light environments and provides an overview of promising technologies immune to this challenge. The paper also discusses the markets that would benefit from requiring sensing solutions with ambient light tolerance.

# Introduction

Depth-sensing technologies have demonstrated considerable efficacy in enhancing productivity across various material handling and industrial inspection applications, resulting in reduced reliance on human labor. Consequently, depth-sensing technologies are progressively penetrating outdoor applications in the agricultural, robotics, and automotive sectors. Nonetheless, current depth-sensing technologies encounter limitations in their effectiveness due to environmental factors such as sunlight and dust. This paper aims to furnish the reader with an overview of emerging markets that necessitate sensing solutions that operate in diverse lighting conditions, and an examination of potential technologies that may address the performance obstacles generated by ambient light, dust, fog, and comparable factors.

# The Sunlight Problem Defined

Numerous depth-sensing technologies currently available on the market function within the visible or near-infrared (NIR) wavelength spectrums, employing active illumination as a component of structured light, indirect time-of-flight (iToF), direct time-of-flight (dTOF), or active stereo approaches. However, when operated in outdoor settings at these wavelengths, these technologies encounter signal-to-noise degradation due to the background light emanating from the sun, leading to a competitive scenario for the depth sensor's signal.

**FIGURE 1: EXAMPLE OF AN ACTIVE STEREO DEPTH SENSOR FAILING IN SUNLIGHT**


Numerous strategies are employed to ameliorate the influence of background light on the returning signal, such as global shutter, narrow bandpass filters, and augmenting the intensity of the active illumination; all of which have contributed to moderate degrees of success. Nevertheless, achieving dependable performance in settings of high ambient light, such as those exceeding 100Klux or in direct sunlight, remains exceedingly arduous.

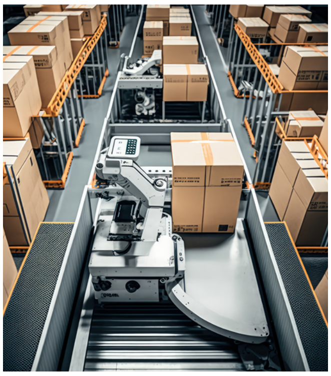
# Outdoor Markets

A large number of growing markets require sensor technologies to support autonomous operation in outdoor environments or environments impacted by bright sunlight. New sensors, with high ambient light tolerance, are required to support foundational requirements such as collision avoidance, obstacle detection, and localization.

**FIGURE 2: RELEVANT MARKETS**

Last Mile

Agriculture



Material Handling

Smart City

## LAST-MILE DELIVERY ROBOTS

The global autonomous last-mile delivery market is projected to grow from USD 11.12 billion in 2021 to USD 51.38 billion by 2028 at a CAGR of 24.4%.[1] The growth is driven by the rise of e-commerce markets, online shopping, and food and retail delivery platforms. Moreover, last-mile delivery robots are expected to reduce carbon emissions and overcome labor shortages in the logistics and delivery industry.[2] The market is witnessing a rise in the manufacturing of autonomous wheeled robot types for various last-mile delivery applications such as healthcare, food and beverage, and retail delivery.

Last-mile delivery robots use different types of sensors for navigation and localization, collision avoidance, and obstacle detection. Data from GPS, LiDAR, force and torque sensors, ultrasonic sensors, cameras, and 3D depth sensors have all been used with different levels of success to fulfill the specific sensor needs of last-mile delivery robotic platforms and drone platforms.

## AGRICULTURE APPLICATIONS

Smart agriculture, also known as precision agriculture or auto farming, utilizes technology to gather, process, and use information from fields, weather, and the environment to improve crop yields, reduce waste, and conserve resources such as water and labor. The global precision-farming market size was valued at USD 9,476.3 million in 2022 and is expected to expand at a compound annual growth rate (CAGR) of 12.6% from 2023 to 2030.[3]

3D cameras provide key sensor data necessary to complete important tasks such as weed and bug abatement, crop-load estimation, crop monitoring, and equipment automation. As important as crop-load estimation is to the efficiency of crop production, challenges remain with capturing quality data in variable lighting conditions. Issues defined in agriculture reports state that "…varying lighting conditions cause non-uniform distribution of light intensity in apples based on their exposure to sunlight at the time of imaging, which may cause improper and incomplete image segmentation. Thus, it would be challenging to develop a robust algorithm to identify apples in variable lighting conditions."[4]

A common yet clumsy solution to improve lighting conditions is the use of portable tunnel structures to create a favorable lighting environment, as shown in Figure 3. The tent structure covers the tree or plant, blocking ambient light during the capture of 2D and 3D imagery.

**FIGURE 3: OVER-THE-ROW (OTR) SENSOR PLATFORM WITH A TUNNEL STRUCTURE.[5]**

Additionally, environmental conditions such as dust, snow, and rain can impede the performance of 3D sensing technologies. These challenges create an opportunity in the precision agriculture market for new technologies to enter that are insensitive to environmental lighting conditions, limit occlusions, and are tolerant to dust and rain.

## MATERIAL HANDLING

The global Autonomous Mobile Robots (AMR) market is projected to grow from USD 1.97 billion in 2021 to USD 8.70 billion by 2028, at a CAGR of 23.7% during 2021-2028[6]. AMRs are used for the retrieval and transport of goods, order consolidation, and work-in-progress movement within factories—as well as other supply chain activities. The penetration of robotics in material handling continues to expand based on the need for greater throughput, increased efficiency, worker safety, and labor augmentation.

The size of an AMR varies depending on its functionality and carrying capacity, ranging from 60kg per unit on the low end to nearly 1,500kg at the high end. [7,8]

Safe operation and successful autonomous navigation depend on the quality of the onboard sensors. Therefore, AMRs are integrated with safety laser scanners for mapping and localization, 3D cameras for collision avoidance and obstacle detection, and camera systems for package selection.

However, the current 3D cameras have limitations in reliably working in sunlight, which restricts AMR operations to indoor environments. Even ambient light from windows and open bay doors can blind depth sensors and impede the safe operation of AMRs. Therefore, new 3D cameras are required to increase safety and expand the operation of AMRs.

## SMART CITY

The global market size for smart traffic cameras was valued at $8.36 billion in 2020 and is projected to reach $32.34 billion by 2030, registering a CAGR of 14.6% from 2021 to 2030. 9 A smart traffic camera is a device that is primarily used for surveillance to improve safety and maintain a smooth traffic flow. These cameras are installed on highways, freeways, expressways, arterial roads, public transportation systems, and in parking garages.

Growing populations concentrated on constrained infrastructure have led municipalities to employ smart cameras to reduce traffic congestion, increase public safety, and provide real-time data for public transportation management. Additionally, these cameras are providing data for planning new infrastructure and public transportation systems. Other factors driving the growth of smart traffic cameras are ticketing and tolls, vehicle tracking, and enhanced security from car thefts.

Because most of these smart cameras are located outside, the sunlight can impede gathering accurate images and data. Cities and towns that rely on smart camera data will benefit from improved imagery with more capable 3D sensors to make important budget and planning decisions.

# Ambient Light Tolerant Solutions on the Horizon

## JABIL 1130NM iToF CAMERA

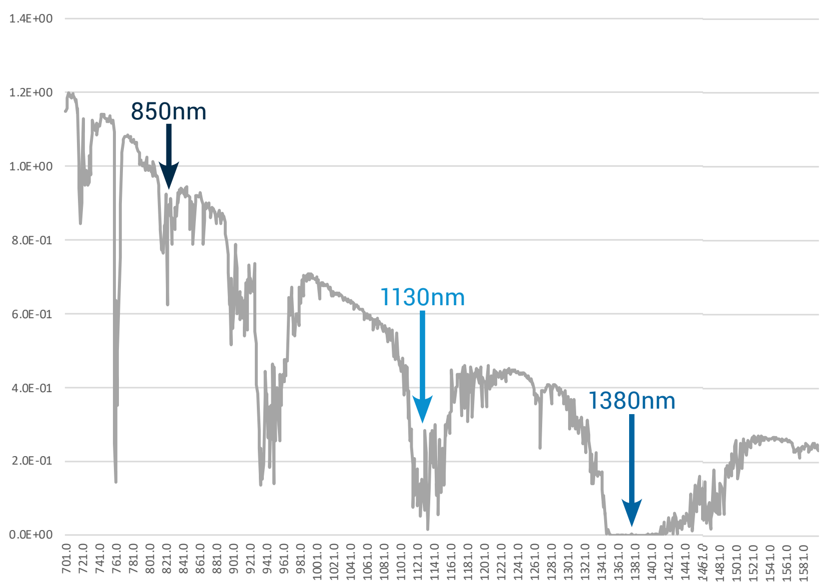
Jabi Optics, in collaboration with ams OSRAM and Artilux, has developed a next-generation 3D camera that exhibits seamless performance in both indoor and outdoor environments, and is capable of operating at a range of up to 20 meters. The 3D sensing architecture design, semiconductor lasers, and germanium-silicon (GeSi) sensor arrays were combined, based on a scalable complementary metal-oxide-semiconductor (CMOS) technology platform, to build this camera that operates in the short-wavelength infrared (SWIR) at 1130 nanometers. This innovative approach improves considerably the signal-to-noise ratio used for depth calculations.

The 3D camera is based on indirect time-of-flight, whereby modulated light at a specific wavelength, such as 1130nm, is emitted. The phase of the reflected light is then used to calculate the distance to an object.

Instead of introducing moderate improvements for technologies within the visible and NIR spectrums, several companies, including Jabil, attempted a more innovative path by developing 3D cameras at the 1130nm and 1380nm wavelengths. Figure 5 illustrates the plot of the sun's solar spectrum and how the Earth's atmosphere absorbs photons from the sun at the 1130nm and 1380nm wavelengths. By targeting these gaps, 3D cameras can enhance the signal-to-noise ratio, as the principal cause of background noise is substantially reduced. Furthermore, the magnitude of the signal can be increased, as the laser eye safety thresholds are higher at 1130nm than either 850nm or 940nm. The outcome is a 3D camera that operates proficiently in direct sunlight, has an expanded operational range, and improves depth accuracy.

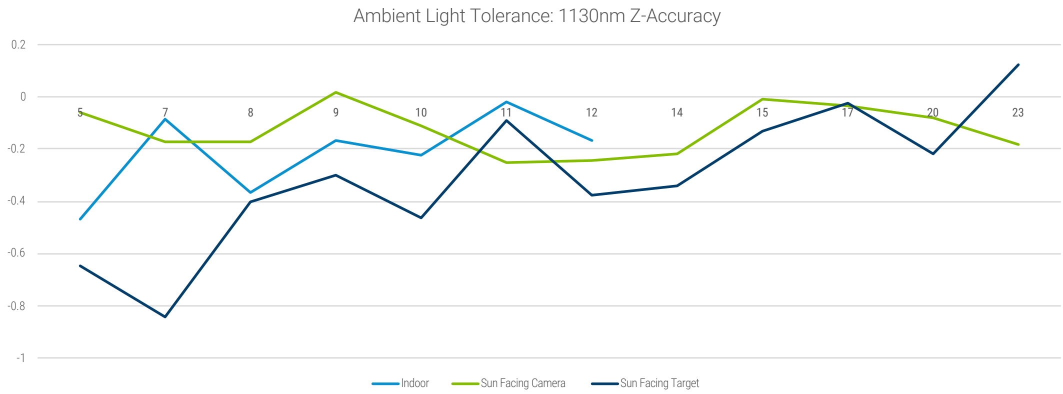
**FIGURE 5: STANDARD TABLES FOR REFERENCE SOLAR SPECTRAL IRRADIANCES**

Data from ASTM International: ASTM-G173



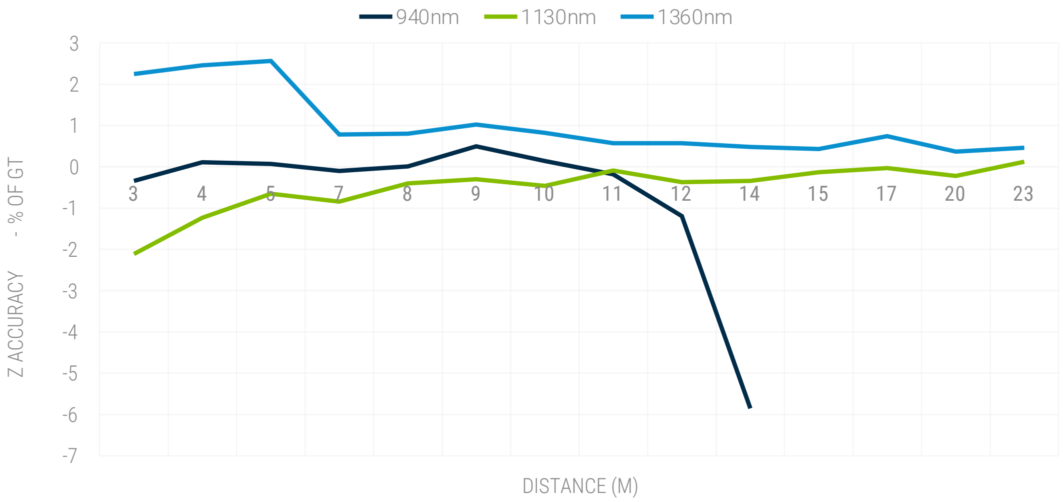
Figures 6-8 provide a sample of the performance testing performed with Jabil's SWIR camera operating at 1130nm and 1380nm wavelengths. The test set up is comprised of capturing flat plane data of a two-meter by two-meter target in three test conditions: indoors, outdoors with the sun facing the target, and outdoors with the sun facing the camera. The testing demonstrated that with an 80% reflectivity target, the Z-accuracy was less than one percent, meaning that there was less than one percent error up to a range of 20 meters. More importantly, the accuracy of the 1130nm camera was closely aligned in all test environments, indicating the sun's impact was de minimis.

### FIGURE 6: AMBIENT LIGHT TOLERANCE



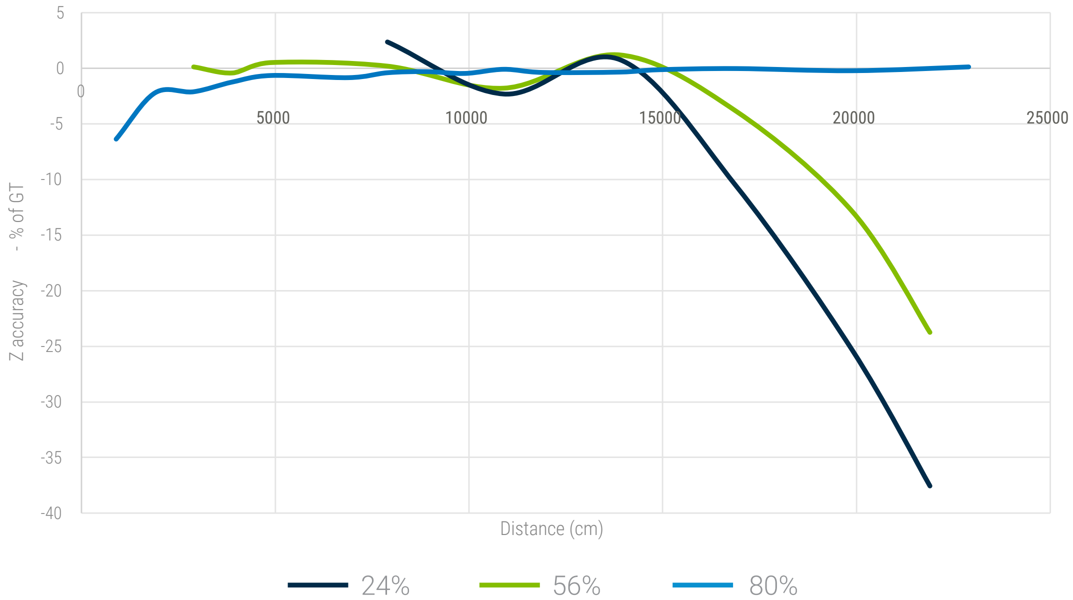

### FIGURE 7: Z-ACCURACY OF ARTILUX SR5 SENSOR USING ILLUMINATION SOURCES AT DIFFERENT WAVELENGTHS WITH 80% REFLECTIVITY TARGET IN 100KLUX

(Camera Facing Sun)



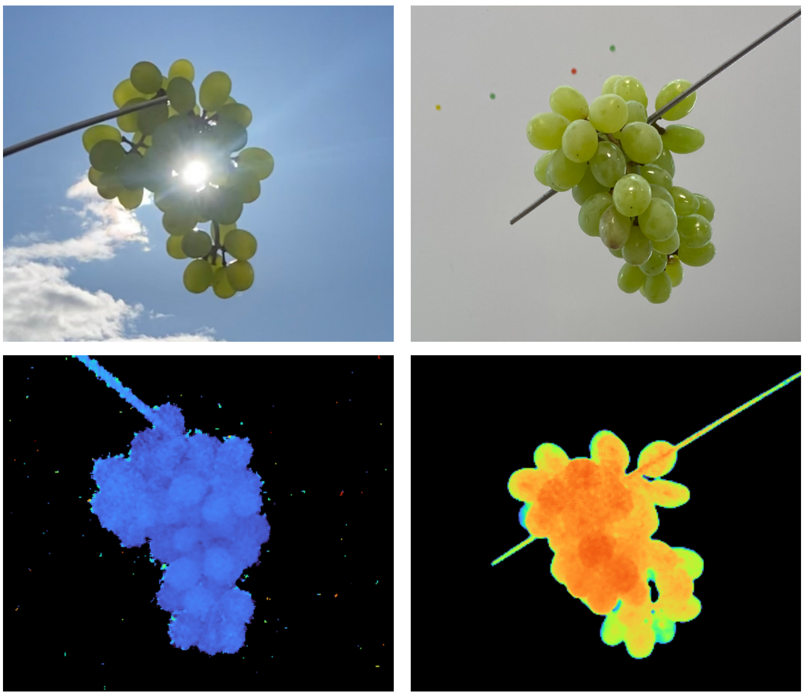
### FIGURE 8: 1130NM CAPTURING TARGETS WITH DIFFERENT REFLECTIVITY IN 100KLUX

(Camera Facing Sun)




Performance testing in real application environments will provide data for sensor optimization, specification refinement, and camera efficacy. Preliminary images shown in Figure 9 capture data of leaves, fruit, and furrows in different agricultural environments.

### FIGURE 9: GRAPE CLUSTER CAPTURED IN AN OUTDOOR AND INDOOR SETTING WITH CORRESPONDING DEPTH IMAGES IN THE BOTTOM ROW



# Cluster Imaging

The approach of Silicon Valley's Cluster Imaging is to lean into the visible spectrum with a depth sensing technology based on multiple cameras, typically four or more cameras. By taking advantage of the trends of decreasing camera costs and processing costs, Cluster Imaging can use multiple cameras to significantly reduce the complexity of the correspondence problem.

Cluster Imaging is currently demonstrating a prototype with eight 2-Megapixel Global Shutter Cameras mounted on a mechanical plate, as shown in Figure 10. The eight cameras are synchronized to an Nvidia processor. The current prototype uses eight cameras to collect depth data up to 200m, six cameras for up to 60m, and four cameras for distances up to 30 meters. The system outputs depth and monochrome data streams for use in object detection and collision avoidance algorithms. A patented feature of Cluster Imaging's multi-camera solution is the ability to auto-calibrate in the field. Unlike traditional stereo systems with a single camera pair, Cluster Imaging can use the results of multiple camera pairs to validate camera synchronization. If one of the cameras falls out of synchronization with the others, the system can autocorrect the camera's calibration in the field.

Clear advantages of the technology are longer range, reduced power, the absence of active illumination, and subsequent laser eye-safety constraints. In testing, mid-range performance was achieved to 45 meters. However, the solution is limited to capturing depth information of edges, baseline constraints common to all triangulation technologies, and day-time operation as the solution relies on ambient lighting similar to traditional photography.

**FIGURE 10: CLUSTER IMAGING 8 X 2MP CAMERA SYSTEM**

**FIGURE 11: OBJECTS @ 40 METERS IN HIGH AMBIENT LIGHT ENVIRONMENT**

# TriEye

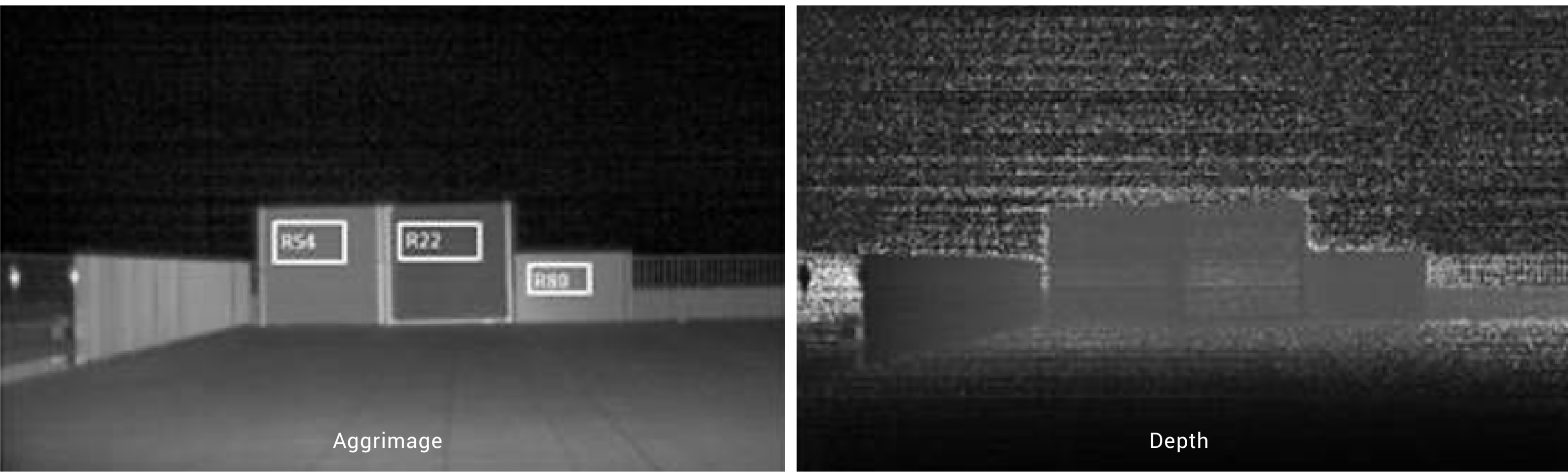
TriEye, an Israeli semiconductor company, has developed a 3D SWIR imaging solution based on a variant of gated ToF called Spectrum Enhanced Detection And Ranging (SEDAR). TriEye's SEDAR is composed of their internally developed CMOS-based 1.3MP SWIR sensor, with an industry leading QE of >50% in the 1300nm-1400nm range. Additionally, the sensor is complemented with their custom-designed high peak power laser illuminator, Image Signal Processing ASIC and depth algorithms.

TriEye initially introduced its SEDAR technology to the automotive market, and has subsequently released an evaluation kit, SEDAR SR & MR, optimized for the industrial and robotics markets, as shown in Figure 12. Key advantages of the technology include ambient light tolerance, enhanced laser eye safety, nearly 40 million depth points per second – orders of magnitude higher than existing LiDAR solutions, and high accuracy. Additionally, the system provides high resolution 2D SWIR images and 3D ranging information.

**FIGURE 12: TRIEYE SEDAR SR EVALUATION KIT**

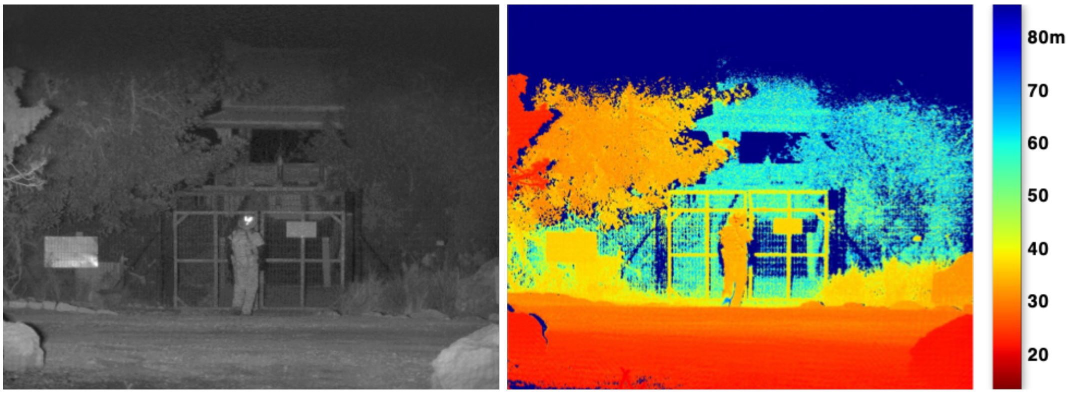

Testing of an early TriEye SEDAR SR prototype provided compelling results for mid-range object detection in high ambient light conditions. Figure 13 shows a 2D SWIR image and a depth map obtained from testing of the TriEye mid-range (SR) prototype with targets of different reflectance in 100Klux conditions. Even with an early prototype, the TriEye system, as tested, was able to achieve a depth error of <3% out to a range of 25 meters.

**FIGURE 13: TEST IMAGERY FROM EARLY SEDAR SR PROTOTYPE**




Distance - 20 meters

### FIGURE 14: SEDAR SR SWIR IMAGE AND DEPTH MAP FOR OUTDOOR OPERATION 20–50 METERS




SEDAR 2D SWIR Image SEDAR 3D Depth Map

Figure 15 compares the SEDAR SR prototype HD SWIR image with a visible camera in outdoor dusty environments. The SWIR image is able to detect low contrast objects in a challenging environment.

### FIGURE 15: SEDAR SR OPERATION IN DUSTY OUTDOOR ENVIRONMENT AT 10 METERS

Visible Camera Image SEDAR SR SWIR Image

Figure 16 shows images of machinery with high contrast details facing the sun in an off-road scenario taken with both a visible camera and the SEDAR SR prototype. The SWIR image provides significant improvement for object detection and classification.

**FIGURE 16: VEHICLE DETECTION IN OFF-ROAD ENVIRONMENT**

Visible Camera SWIR Camera

TriEye continues to investigate how to better optimise their technology per application. This includes tailoring the power consumption of their laser illuminator, and their ability to detect low reflectivity and highly specular objects, the dependency of the exact wavelength and human skin detection. These challenges are common to most NIR and SWIR imaging systems.

# Vision of Future

Jabil tested several early-stage 3D sensing solutions with claims of high ambient light tolerance. These novel 3D sensing solutions are expected to be available to the market within the next two to five years as they tackle challenges such as supply chain, cost reduction, power efficiency, and performance optimization. The introduction of new component technologies is also expected to increase the breadth of 3D sensing solutions operating at 1130nm and 1380nm. Additionally, advancements in pixel technologies, illumination technologies, and algorithms will provide competitive solutions that will blur the lines with LiDAR solutions targeted at short and mid-range applications.

Jabil Optics plans to offer evaluation kits of its 1130nm iToF solution for early adopters in the robotics, material handling, and agriculture markets in late 2023.

# About Jabil Optics

For nearly two decades, Jabil Optics has been recognized by leading technology companies as the premier service provider for advanced optical design, industrialization, and manufacturing. Our Optics division has more than 170 employees across four locations. Jabil's optics designers, engineers and researchers specialize in solving complex optical problems for its customers in the automotive, industrial, consumer and healthcare markets. Thanks to our many years of experience in working with start-ups and Tier-1 companies, we can offer our customers tailored advice at every stage of development. Jabil is the most advanced solution provider outfitted to handle the complete product design cycle from ideation to high volume production. Additionally, Jabil customers leverage expertise in product design, process development, testing, in-house active alignment (from Kasalis, a technology division of Jabil), supply chain management, and manufacturing expertise. Jabil is one of the world largest manufacturing service providers with more than 100 locations worldwide and one of the strongest supply chain, logistics, and quality organizations in the industry.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| AGV | Automated guided vehicle |
| AMR | Autonomous mobile robot |
| CAGR | Compound annual growth rate |
| CMOS | Complementary metal-oxide-semiconductor |
| dToF | Direct time-of-flight |
| GeSi | Germanium-silicon |
| iToF | Intensity-based time-of-flight |
| NIR | Near-infrared |
| SEDAR | Spectrum Enhanced Detection And Ranging |
| SWIR | Short-wavelength infrared |
| ToF | Time of flight |

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