Latest Trends and Future Directions in Ultra-High-Definition Imaging Technology Accelerating Smart Industry

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1. Introduction

4K and 8K ultra-high definition imaging technology is being used to improve image quality in broadcasting, but it is also being used in various other fields, such as to display advertising on outdoor displays, to implement ultra-high-definition systems for security and crime prevention, and for medical applications. In industry, where smart technologies are being used to increase productivity dramatically as we enter the IoT age, high-definition and high-quality images can be taken, and there is increasing use of sensing technologies utilizing infrared and other images not visible to the human eye. Image sensors are a key type of device necessary for these advanced types of machine-vision camera. Industrial image sensors require high quality and continuous availability. Industrial applications vary widely, so a significant feature of this market is the need for a broad product lineup. We are a leading company in image sensors, with a broad portfolio of products covering small to large, low to high-speed, low to high pixel counts, and from ultra-violet through infrared frequencies, to meet all kinds of requirements. Each series is also packaged with uniform pin-outs, so it is easy to develop product lineups when developing machine vision cameras.

This article describes our vision for advancement of image sensors for industrial applications and introduces some examples of practical applications. Figure.1 shows our vision for the evolution of image sensors in the future. We have defined three directions for advancement. The first is to improve the performance of our base image sensors, the second is to extend performance from imaging to sensing, and the third is to optimize functionality for edge systems. We describe each of these perspectives in detail below, and also give examples of related machine vision cameras systems.

2. Advances in imaging performance

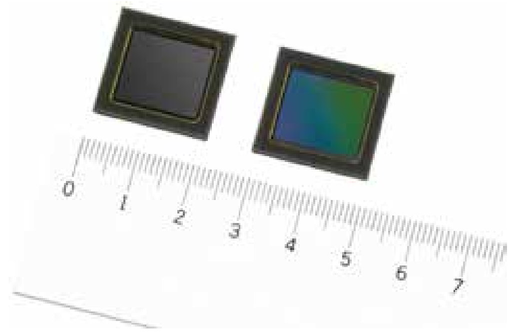
To implement advanced automation in areas such as factories or logistics requires improved efficiency by increasing the accuracy and decreasing the time required for inspections. For machine vision cameras, which handle most of these functions, this requires image sensors with higher imaging performance in terms of resolution (higher definition), higher speed, and other factors. This section examines typical image sensor performance improvements in the areas of increasing resolution while reducing size, and technologies to improve productivity by increasing image-sensor size while accelerating data read-out.

2.1 Achieving both higher resolution and smaller size

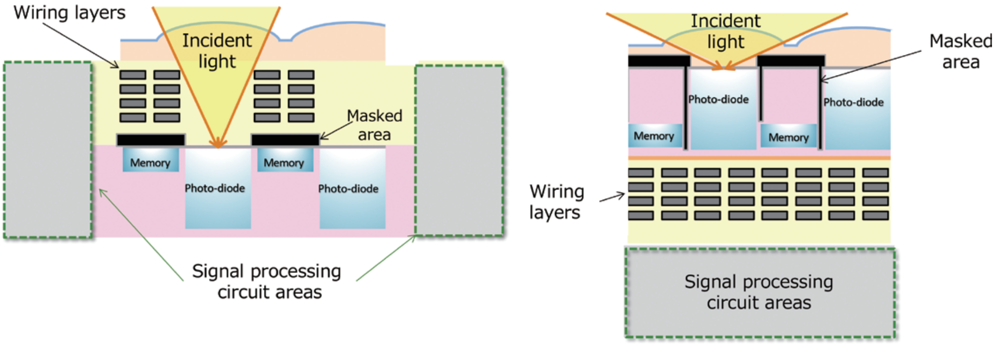
When attempting to improve accuracy for visual processes detecting small defects or contamination, simply increasing the pixels in the image sensor results in larger chip size and larger cameras, which can be an issue. Conversely, if the pixels are made smaller to avoid increasing the camera size, the light-collecting area per pixel decreases, leading to decreased image quality and unavoidable decreases in recognition and detection performance. To resolve this issue, we have developed a layered CMOS image sensor technology called Pregius S™ (Figure 2, 3) that is suitable for industrial applications. It has a "Global Shutter" feature that uses a back-illuminated pixel structure to achieving both high resolution and smaller size. The new structure is able to collect more light per pixel than conventional front-illuminated structures, and we developed technology to mask the memory components in our global shutter function, so that pixel characteristics are not compromised, so we were able to reduce pixel size to 2.74 µm diagonally, or 63% of earlier pixels. By

■ **Figure 1**

■ **Figure 2**



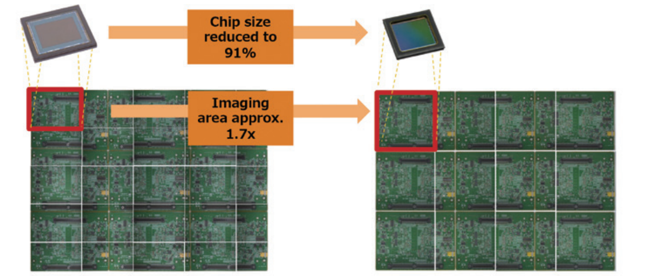
■ Figure 3



Earlier front-exposure structure with Global Shutter function

New layered structure with Global Shutter function

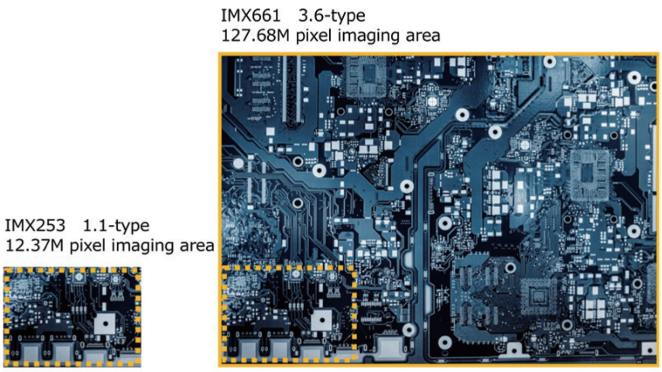
■ Figure 4



Earlier product: IMX253 (12.37M pixels) x 25 images

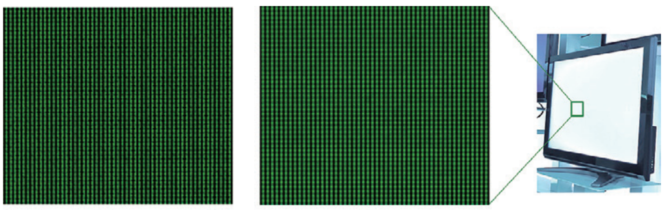
New product: IMX531 (20.35M pixels) x 12 images

■ Figure 5



* Using a lens with the same focal distance, the IMX661 on the right captures approximately 10-times the area of the IMX253 on the left.

■ Figure 6



Capture at low resolution (moiré pattern)

Capture at high resolution (no moiré pattern)

layering the signal processing circuits, which were conventionally placed in beside the pixels, we have also increased resolution by approximately 1.7 times for the same optical system (from 12.37 M pixels to 2.035 M pixels) and reduced the package size (to 91% of earlier[*1]) (Figure 4).

2.2 Image sensor technologies for larger size and faster readout

Some machine vision cameras use an image sensor that supports ordinary C-mount lenses, but further productivity increases can be obtained by using an image sensor with a larger optical size to increase the imaging area. For example, comparing our IMX235 image sensor, which is 1.1-type (diag. 17.6 mm) and has 12.37 M pixels, and our large-aperture IMX661 image sensor, which has our Global Shutter function, is 3.6-type (diag. 56.7 mm) and has 127 M pixels, productivity can be increased by reducing the number of images captured, and recognition accuracy can be improved with the higher resolution (Figure 5). For inspection of flat panel displays, if the image sensor resolution is too low relative to the resolution of the panel, moiré patterns occur as shown in Figure 6, so inspection with oversampling using an ultra-high-definition image sensor is very useful. On the other hand, when the number of pixels is increased, generally the amount of signal processing required also increases, the frame rate decreases and more time is required to read out the data. With the IMX661, we used a Chip-on-Wafer process technology to create an original device structure, layering a chip with some of the functionality onto the pixel wafer and increasing processing performance by implementing AD converters in an optimized location. We also used a high-speed interface called Scalable Low Voltage Signaling with Embedded Clock (SLVS-EC) to achieve a four-times increase in image read-out speed* . For inspection

*1 Comparing our IMX531 and IMX253 CMOS image sensors with the Global Shutter function. “Pregius S” is a trademark or registered trademark of the Sony Group and related companies.

of devices such as flat-panel displays and printed circuit boards, cameras with large-aperture image sensors are being used more and more. Larger areas to be imaged in a single shot by using of larger image sensors and fast read-out technology, reducing both the number of images taken and the inspection time, and inspection accuracy can be improved by increasing resolution.

3. Extending capabilities to sensing

Recently, the use of sensing beyond the capabilities of human vision is advancing in the field of industrial machinery. In addition to conventional inspection and recognition using visible light, new information such as near-infrared, polarized light, and distance data is being captured, making it possible to solve problems that could not be solved earlier with sensing. In this section, we describe four of these various new sensing technologies: Short-Wavelength InfraRed (SWIR) image sensors, Ultraviolet (UV) light image sensors, Time-of-Flight (ToF) range-imaging sensors, and polarized-light image sensors.

3.1 SWIR Image sensors

SWIR is a type of infrared light with relatively short wavelengths. In 2020, we announced our IMX990/IMX991 image sensors, able to capture images over a wide range of wavelengths that include visible light, from 0.4 µm to 1.7 µm. When developing SWIR sensors, we formed photodiodes in a layer of the compound semiconductor, Indium-Gallium-Arsenide (InGaAs) and the read-out circuits in a silicon layer, making copper-copper (Cu-Cu) connections between them. This enabled us to reduce the pixel pitch, achieve wide bandwidth and create an image sensor supporting SWIR, which was not possible earlier.

SWIR wavelengths can be used to visualize damage to fruit below the surface (visualizing differences in moisture density) as shown in Figure 7, or to select materials utilizing differences in absorption of short-wavelength infrared light. The new sensor can be used as a more versatile inspection device to reduce system costs, by using a single device for inspection that previously required separate cameras for visible and SWIR light, or to increase throughput, by accelerating image processing.

3.2 UV image sensors

Sensing with ultra-violet (UV) light can be useful for selecting materials difficult to differentiate with visible light, or to detect fine scratches or defects. UV light has wavelengths that are shorter than visible light, generally in the range of 10 nm to 400 nm (Figure 8). Our IMX487 image sensor detects wavelengths from 200 nm to 400 nm, and is suitable for industrial sensing using UV wavelengths. Used with a UV light source, it shows promise for a wide range of use cases, including detecting semiconductor pattern defects, differentiating materials for recycling (Figure 9), and detecting minute scratches on the surface of parts. This product has a structure specialized for sensing UV wavelengths, and is equipped with our Pregius S technology, so it produces high frame-rate images without motion distortion. We expect it to expand the range of applications for UV image sensors, including those requiring high speed.

Figure 7

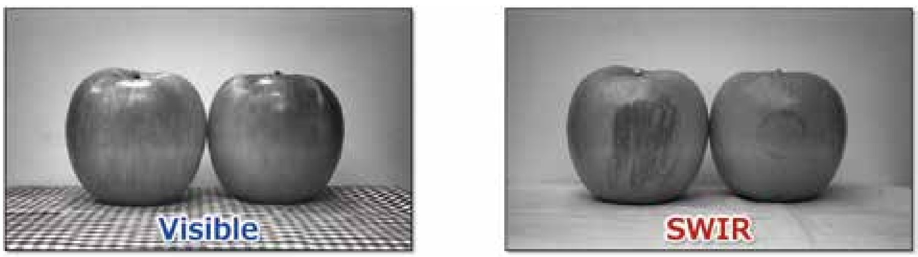
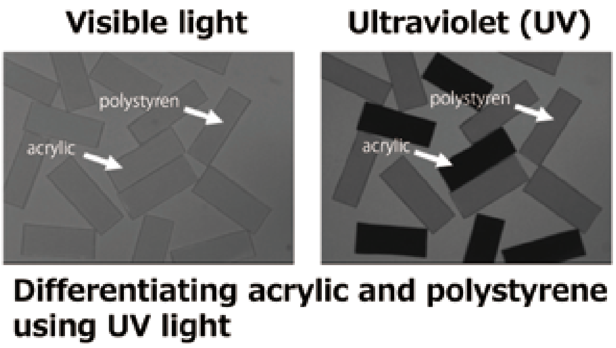


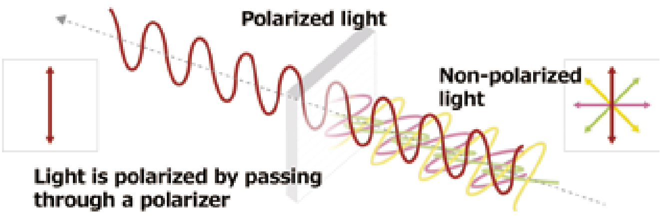
Figure 8

*2 Comparing our IMX661 and IMX253 sensors with the Global Shutter feature.

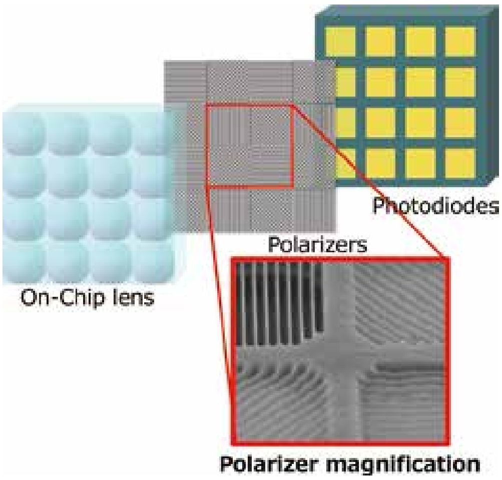
■ Figure 9



■ Figure 10



■ Figure 11



3.3 Polarized light image sensors

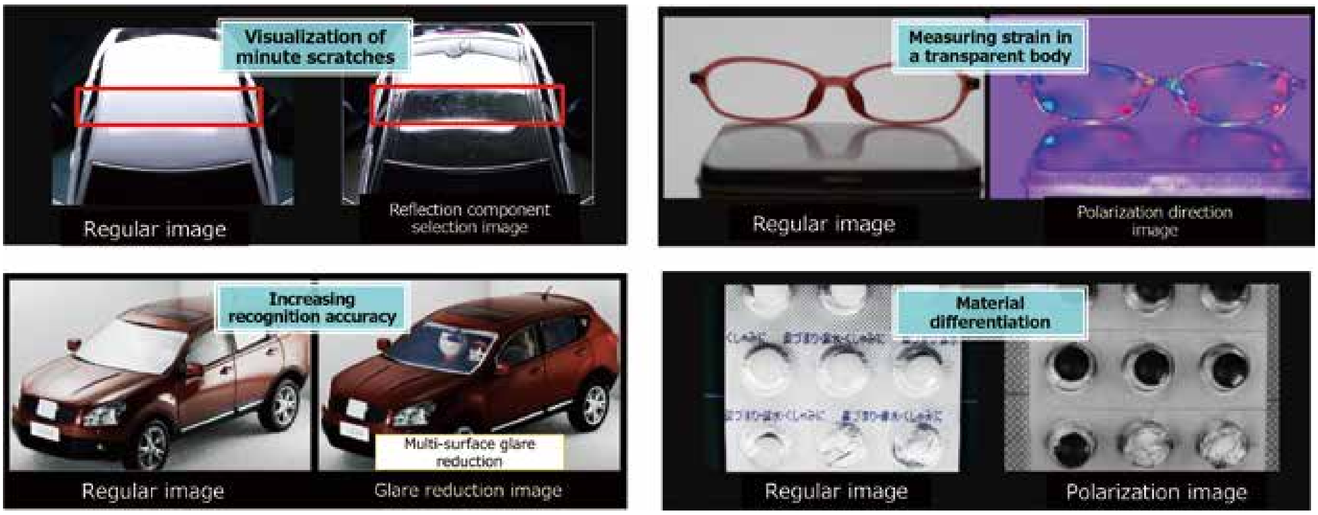
Normally, when looking at an object, we see both light that is reflected and light that is diffused from the surface of the object. This light oscillates in different directions and it is possible to select light oscillating in a particular direction (polarization) by passing it through a polarizer (Figure 10). Our polarizing image sensors (e.g.: IMX253MZR) are equipped with internal polarizers for four directions and are able to capture polarization data for these four directions in a single image (Figure 11). As shown in Figure 12, this polarized light data can be used to increase the accuracy when detecting scratches, impurities or distortion on the surface of objects or to eliminate reflected light, which are difficult using conventional visible-light sensing,. We expect this to enable a range of other applications in the future.

3.4 Time of Flight depth-image sensors

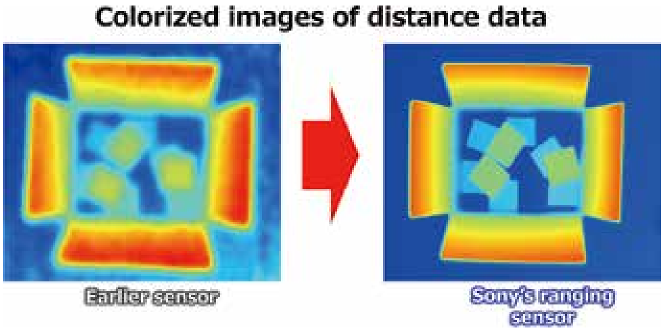
A Time-of-Flight (ToF) depth-image sensor uses light from a laser or LED to measure the distance to the object, by measuring the differences in time required for the reflected light to reach the sensor. We announced the IMX570 image sensor in 2021, as a compact, high-resolution sensor capable of sensing in 3D space (Figure 13). It was developed for applications that are difficult to implement with conventional 2D images, such as those requiring detection of volume or shape, or overlapping of objects.

By providing this lineup of various sensing devices, we are contributing to solving problems in manufacturing settings such as eliminating failure, increasing throughput, eliminating line stoppage, reducing labor requirements and automation.

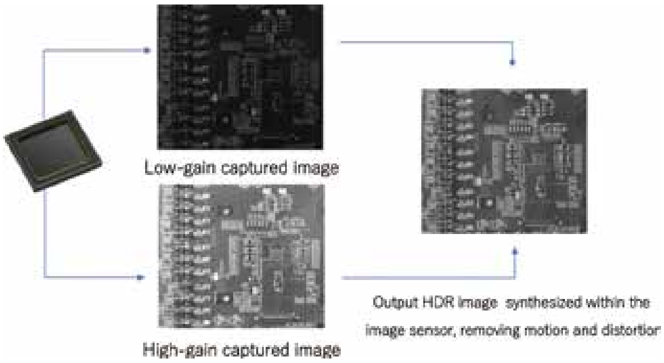
■ Figure 12



■ Figure 13



■ Figure 14



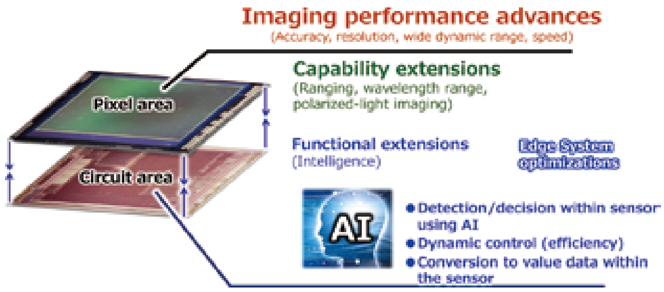
4. Functional extensions optimized for edge systems

Conventionally, image sensors have been developed with the assumption that human eyes would be looking at the images, and sensors would output images in terms of effective pixels. However, when used by AI or other machines, all of the pixel data will not necessarily be required. For example, when inspecting printed circuit boards, it may be enough to inspect only specific components or locations. In such cases, pixel data from other locations is not needed and capturing the extra data increases the time required from image capture till peripheral devices can take action. Even when considering the simple imaging devices described in earlier sections, the amount and types of data is increasing greatly, with more pixels, faster speeds, and additional data such as polarization and distance. As inspection of components advances and camera resolution increases, the volume of information will increase dramatically, also increasing the processing load for image processing and interface circuits at later stages.

As such, when considering AI and other machine processing, it will be useful to extract only the regions needed, to reduce the amount of data and the required processing time. Our image sensors have a Region of Interest (ROI) function to extract only the area needed, and a self-triggering function to output only data from the instant required. They are also equipped with two AD converters in a layered implementation, which can read data at two different levels of gain, and they have functions to synthesize these values internally. High Dynamic Range (HDR) processing, which is normally implemented by overlapping multiple images, can be performed by synthesizing the images within the sensor, without producing artifacts, and we have implemented highly-robust sensors able to output the same amount of data as earlier sensors (Figure 14).

This sort of extended functionality can be implemented using layering technology. As shown in Figure 15, a key point regarding the layering technology is that the wafer process is separated into a pixel region and a circuit region. This makes further image-quality improvements and functional enhancements both more scalable. Techniques applied to the wafer process can also be extremely useful in reducing latency, implementing feedback to

■ Figure 15



pixels and reducing power consumption. Extending functionality will surely be helpful as AI is used more and more in the future. It will be extremely important how this overall issue is handled, including later-stage system processing, and we are continuing to work on both hardware and software solutions for these issues.

5. Conclusion

This article has introduced directions for advancement of image sensors (advancing and extending performance and functionality) as considered by Sony Semiconductor Solutions. We have over 120 types of products developed along these directions, to meet a wide range of requirements in industry. We will continue advancing innovation in image sensor technologies, cultivating new applications, accelerating smart industry, and contributing to improving lifestyles and solving societal issues. For product details and inquiries regarding image sensors for industrial equipment, please see the following address.

https://www.sony-semicon.com/en/products/is/industry/index.html