



**Sharper Vision,  
Smarter Machines**  
Image Sensors for  
Drones and Robotics



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## A Revolution in Perception

Any mechanism designed to function and move autonomously or semi-autonomously relies upon some representation of where it is and where it's going. This tutorial deals with two classes of such mechanisms:

- ▶ **Unmanned Aerial Vehicles (UAV)** — Aircraft designed to be programmed to guide and navigate themselves, usually at low altitudes, avoiding obstacles along the way and compensating for unpredicted weather patterns, to enable large areas of land or property to be visible from above
- ▶ **Vision-Guided Robots (VGR)** — Mechanisms programmed to ascertain the most optimal course of movement for themselves to achieve their assigned tasks, based on information they ascertain in real-time through any combination of visual imaging, mapping, and depth sensing

UAVs and VGRs are both evolving. Their architecture is being innovated to make better use of the information they sense from the world around them. As they evolve, they become subdivided into classes. During this evolutionary process, how each class implements the data from its image sensors, and uses that data to coordinate its activities, becomes its own unique strategy. Today, each class is defined not only by how it moves and what it does but also how it sees.





**AltiGator OnyxStar FOX-C8 XT Observer**  
*[image by ZullyC3P, licensed under CC 4.0]*

## The Types of Commercial UAV Drones

There are now three principal classes of UAV units in the commercial market, each of which has an evolving sight strategy that distinguishes it further from the others.

### Rotary Drones

Single-rotor and multi-rotor drones comprise the most common variety, identifiable by their helicopter-like horizontal rotors, sometimes just one but often as many as eight, perhaps more. They are capable of vertical take-off and landing (VTOL), and are operated at relatively low altitudes. Flying a rotary drone manually is a genuine skill, so not only its ability to perceive its environment but to communicate that information immediately and thoroughly to its pilot, become critical for safety.

In Australia, rotary UAVs are put to use regularly in bushfire management operations. When a bushfire ignites within a remote region, a rotary drone can be deployed and make its way to the fire scene in a matter of minutes. There, it deploys a variety of image sensing mechanisms simultaneously, including thermal sensors and infrared, to immediately communicate back to base the fire's spread and speed. This way, incident commanders have an opportunity to develop firefighting plans as their fire crews are on their way to the drone site.



**MQ-27 Scan Eagle**  
*[US Navy public release]*

## The Types of Commercial UAV Drones

### Fixed-Wing Drones

A drone with a vertical propeller and a fixed wing is essentially a model airplane equipped with image sensors and often with supplemental lasers. Forward image sensors enable this drone to be piloted remotely, and to cover longer distances without the need to stay within visual range of the pilot. This class of drone is frequently put to use in land surveying, mapping, agricultural research, and aerial reconnaissance.

Although drones based on model plane chassis may be launched from runways, some are launched from catapults. Lightweight models may be thrust into the air, perhaps just by hand or using projectile launchers the size of small hunting rifles. In the case of the **U.S. Navy's MQ-27 Scan Eagle**, pictured here, two airmen launch and retrieve the aircraft, while two other personnel are kept at standby for maintenance. The UAV is equipped with long-range reconnaissance cameras and infrared (IR) cameras. At the end of a mission, it's retrieved from the air using a hook attached to its wing tip which snags a rope attached to 50-foot poles. Scan Eagle is so durable and stealthy that one unit can log more than a half-million combat hours.



**UC Berkeley hybrid VTOL cargo drone**  
*[image released by UC Berkeley under  
Creative Commons]*

## The Types of Commercial UAV Drones

### Hybrid Rotary Drones

A hybrid drone has the extra virtue of VTOL, so it doesn't have to be launched in a clearing or an area without obstructions to attain enough forward velocity to stay aloft. Taking a cue from the venerable Bell Boeing Osprey military aircraft, a hybrid drone's rotors tilt horizontally from the launch point to bring the unit to safe altitude, then rotate into a vertical position to produce forward-moving lift under the wing.

In rugged terrains and difficult environments where long-distance surveillance or mapping is the objective, hybrid drones have proven to be ideal tools. Capable of flying over extended ranges, a hybrid drone has the capability to scan wide areas of terrain, often using thermal imaging to see beneath coverings to locate trapped or wounded people and animals in need of rescue, or to keep up with moving vehicles in pursuit situations.

## Demand Drivers for Drone Applications

In July 2025, the U.S. Secretary of Defense ordered the Pentagon to take bold steps to ramp up its acquisition and deployment of drone technology for Defense operations. That November, the U.S. Army announced its intention to purchase a minimum of 500,000 drones over a two-year period, representing a tenfold increase in drone procurement.

At that time, commercial market analysis firm Research and Markets estimated that total market activity for U.S.-based drone manufacturers for 2025 would total USD\$28.44 billion. Over a five-year period, the firm projected the market would grow at a compound annual growth rate of 13.0%, reaching USD\$52.51 billion by the end of 2030.

While defense operations was obviously one driver, the firm also cited last-mile airborne package delivery, emergency response and support, environmental ecosystem monitoring, agricultural asset management, and a new category of physical security: airspace management. It's an aspect of security that enables property owners to oversee the monitoring of their property in real-time from the air, as well as assist in the thwarting and apprehension of intruders.

### Drone applications

<b>Defense</b>	ISR (Intelligence, Surveillance, Reconnaissance) Combat, Loitering Munitions, Electronic Warfare, Tactical, Border Security, Maritime Security
<b>Public Safety</b>	Law Enforcement, Terrorism, Hostage Rescue
<b>Inspection</b>	Construction, Real Estate, Utilities, Pipelines
<b>Public Services</b>	Fire Detection & Mapping, Disaster Management, Search & Rescue, Traffic Monitoring
<b>Delivery &amp; Logistics</b>	Retail, Medicines
<b>Surveys &amp; Monitoring</b>	Agriculture, Environmental & Ecological
<b>Industrial</b>	Inventory Scanning
<b>Other Commercial</b>	Filming, Pro-Photography, Precision Agriculture

## How a UAV Perceives Its Environment



The two principal imaging systems for a drone are for **navigation** and for **vision**. The sensors involved with these functions are fundamentally different from one another in both their design and operation.

### Gimbal-mounted image sensors

The front-mounted gimbal of a UAV is effectively its “head.” Although historically gimbals have been used to mount gyroscopes for aircraft and spacecraft navigation, for drones, gimbals are necessary to enable the vehicle to track at least one object independently of the scene in front of it. To that end, the gimbal is given the ability to pitch and tilt itself, although when a 360-degree scan is necessary, it’s often academic for the UAV to hold its position in the air while rotating.

Today, a drone gimbal is such an important part that an entire industry has developed around just the gimbal, separate from the rest of the aircraft. A gimbal typically supports as many as three types of cameras, in any of the following categories:

- ▶ **First-person view (FPV)** — analogous to the line-of-sight of a human-crewed aircraft’s passenger)
- ▶ **Thermal / infrared or near-infrared (NIR)** — providing the ability to register heat levels emanated from the surface of a photographed object, often to detect living creatures or sources of dangerous heat or substances
- ▶ **Telephoto** — often equipped with a higher-resolution image sensor, often with sub-micron pixels that expand the spatial resolution to better distinguish differences in contrast and dynamic range; or with longer focal-length lenses with 2x to 5x optical zoom

## How a UAV Perceives Its Environment

### Collision avoidance systems

The functions and algorithms of a drone's collision avoidance system are located in its electronic control unit (ECU). It's part of the UAV's firmware or software. Unlike a ground-based autonomous vehicle, everything the UAV must process in time for it avoid any obstacle it has detected, must reside within the unit locally — not in the cloud or a remote processor.

This is why such a system requires more than one data source: sensor data from the gimbal, range and distance data from radar or LiDAR, and mapping coordinate data from GPS. An airborne collision avoidance system (ACAS) is the formal standard for a method of averting mid-air contact, often autonomously. ACAS was developed for all aircraft, and now some form of ACAS is being adapted for use in autonomous aircraft.

### Visual Navigation Systems (VNS)

Integrated into the same hardware and image sensor systems is the UAV's Visual Navigation System. Although a collision system may only require one FPV camera, if it has two, they can be made to work in tandem. Acting in stereo, and providing the ECU with sequences of adjoining frames, they provide a VNS with visual odometry — the capability to estimate position and orientation, and deduce distance traveled, by matching the apparent locations of landmarks such as intersecting streets with their estimated coordinates in internal map data.

### Simultaneous Localization and Mapping (SLAM)

This coupling of visual data with mapping data is a methodology called Simultaneous Localization and Mapping. A drone said to be equipped with SLAM should be capable of estimating not only its position but projecting a course for itself, should one source of data or perhaps both be rendered unavailable. For instance, SLAM would be able to direct the UAV's guidance system to change course to avoid an object believed to be in its path, if it deduced that object's bearing and velocity using both odometry sources, but can only project a course change for itself using just one source.



## How the FAA Plans to Expand Drones' Abilities

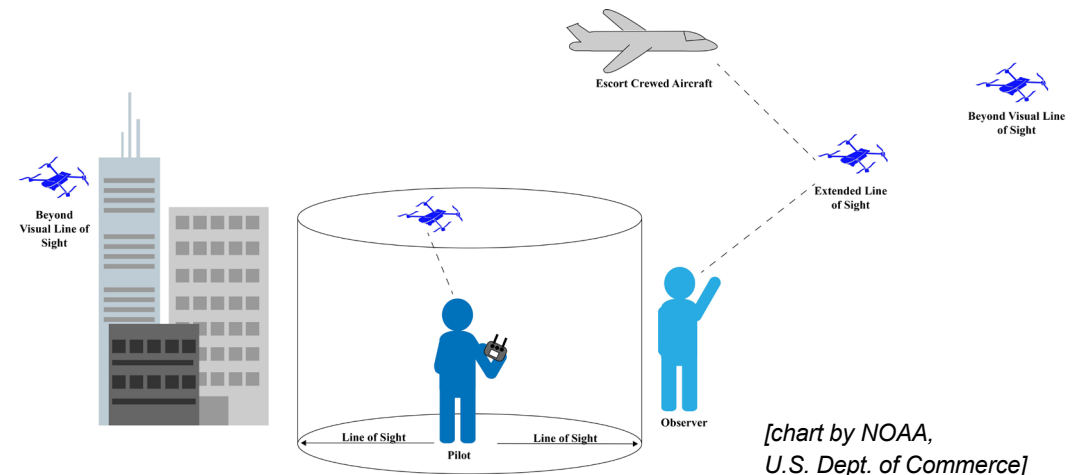
### Beyond Visual Line of Sight (BVLOS)

Most hobbyists' drones are intended to be operated in the limited area of space within the pilot's line of sight, like a model plane. Such a vehicle doesn't require transmitting camera data or coordinates back to the ground-based pilot. So what distinguishes a hobby drone from a professional commercial vehicle tends to be the ability to extend its operating range beyond what the pilot's eyes can see — beyond the visual line of sight (BVLOS).

Up until now, drones whose total weight, including cargo, exceeds 55 pounds must be granted special operating exemptions from flight restrictions under 14 CFR Part 107. In August 2025, the U.S. Federal Aviation Administration has proposed new rules and regulations that would expand the permitted activities of small, non-crewed aircraft designed for flight below 400 feet of altitude.

The new rules would authorize the FAA to evaluate proposals by UAV operators to operate drones equipped for BVLOS flight, and to approve those proposals on a case-by-case basis. Drones approved for flight under the new rules would be permitted to carry cargo weighing up to 1,320 pounds.

To meet the FAA's strict safety standards, however, every approved BVLOS-ready drone would need to be capable of broadcasting their locations the way all other commercial aircraft do in North America: using the AVS-B standard. This standard mandates continually sending GPS location, altitude, and speed data on standard radio frequencies. For a UAV to meet these requirements, it must be equipped with collision avoidance, VNS, and SLAM. Therefore, the UAV would be required to be equipped with both imaging and depth-sensing devices.



## The Types of Industrial Robots

### Articulated Robots

A device does not need to be capable of locomotion to qualify as a fully-fledged robot. Indeed, perhaps the most common form of robot in use today is the articulated robot, which often borrows design principles from the human arm to incorporate rotary joints along from two to ten axes, usually enabling at least six degrees of freedom — while being secured to its station. Such an industrial robot is used in component assembly, welding, painting, and material handling, and in the case of the adjacent photo, palettizing loaves of bread. For articulation to be precise, modern robots incorporate a variety of image sensors in places you would not expect to find them in nature, such as the tips of what pass for their “fingers.”



*An articulated robot produced by KUKA Roboter GmbH for a bakery in Germany. [Public domain image]*

### Automated Guided Vehicles (AGV)

An AGV is a category of industrial robot that only requires a minimal degree of vision. In a warehouse, AGVs are employed to deposit, sort, and retrieve goods from and to inventory shelves. If an AGV is given an extensive enough map of its warehouse, it can usually estimate its location well enough by keeping track of the motion of its own wheels or traction system. However, modern AGVs supplement this information with visual data from cameras, and for larger operations, depth-sensing data from lasers or IR devices. At minimum, all an AGV needs to guide its course is a reflective stripe painted on the floor, which the mechanism is programmed never to stray away from.



*A hospital transporter that stays inside its boundary strips. [Hospital La Fe de Valencia, photo by Mgonezrobotnik, CC 4.0]*

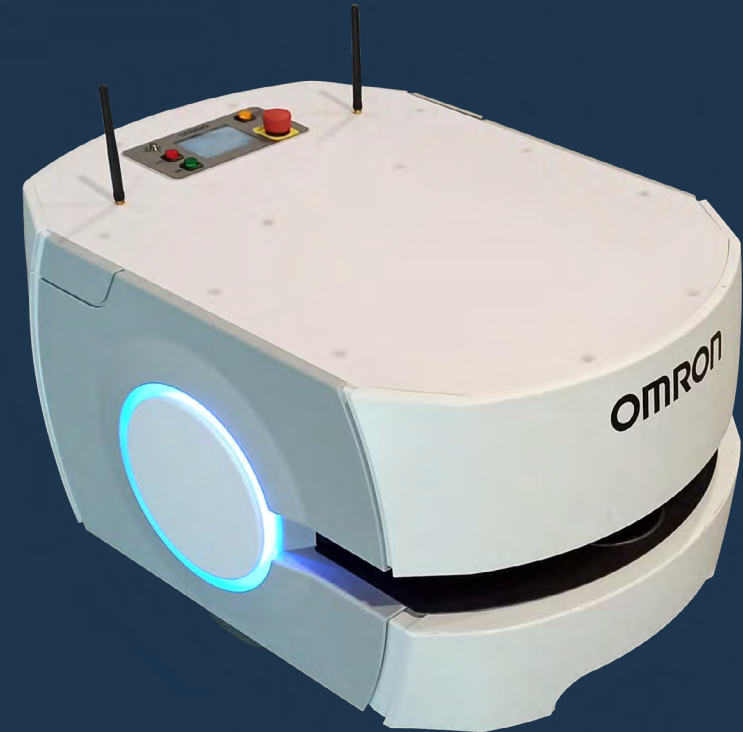
## The Types of Industrial Robots

### Autonomous Mobile Robots (AMR)

What differentiates “autonomous” from “automated” is what distinguishes an AMR from an AGV: the degree to which it’s able to move on its own, without direct guidance from paint on the floor or markings on the wall. Like a BVLOS drone, an AMR is capable of moving within any environment in which it happens to find itself. It uses collision avoidance, VNS, and SLAM to navigate its environment, including in areas and locales that have not been mapped for it in advance.

Within the ECU of the AMR are methods and algorithms for establishing bearing and heading. The AMR’s programming enables it to leverage this data. This gives the robot all the support it needs to accomplish the tasks it needs to move autonomously, including environmental navigation, three-dimensional mapping, and depth sensing.

As AMRs learn to adapt to different terrains, including outdoors, it becomes necessary to integrate adaptive features into their imaging systems. These features include increased sensitivity for low-light conditions, and support for high dynamic range (HDR). The more adaptive an AMR design’s vision system can become, the more standardization and generalization may be applied to its architecture. This way, a factory no longer needs to retool an existing design, or come up with an entirely new, bespoke design, whenever it needs new robots for an emerging application.



Omron LD AMR [image by Auledas for Omron, released under Creative Commons 4.0]

## The Types of Industrial Robots

### Humanoid robots

The interest in robots that look and move like humans continues to steadily grow throughout industries. When a robot is designed not just with the shape of a human but the movement characteristics of one, the optimum location for its imaging components ends up being its “head.” Here in the robot’s endoskeleton, the head can utilize gyroscopes and balancing sensors to maintain stability, not unlike the function of the human inner ear. However, a humanoid isn’t limited to just two “eyes.” Conceivably it may employ the same array of imaging devices as for any AMR or BVLOS drone, although some of those devices may be obscured behind, for example, a polarized or one-way reflective shield for cosmetic reasons.



**Hexagon Aeon humanoid robot**

*[image by Hexagon, released to the press in 2025]*

### Robotic exoskeletons

In recent years, researchers partnering with commercial robotics firms have developed robot exoskeletons designed to assist people in motion, including hikers, athletes in training, and more commonly mobility-challenged people. Although the wearers of most robotic exoskeletons are presumed to have their own vision, or other means of sensing their own environments, exoskeletons cannot yet deliver sensory information to their wearers’ brains.

In light of this fact, exoskeletons are incorporating imaging systems, even in places where you would not expect to find eyes. One manufacturer of a lower-body exoskeleton designed to assist in hiking and long-distance walking uses stereo cameras positioned along either side of the wearer’s waist, along with laser depth-sensing located alongside both knees, pointing down towards the ground to ascertain the height of nearby steps, inclines, and gradients. Some designs being tested for assisting people with arm and hand motion include embedded cameras within the palms of their gloves.

## The Types of Industrial Robots

### Hybrid Drones + Robots

In October 2025, Caltech University publicly demonstrated what it characterizes as a “humanoid-drone hybrid robot system,” effectively operating both types of platforms as one. Its X1 platform is based around a humanoid robot capable of navigating a variety of land terrains, equipped with its own autonomous motion systems. Attached to the humanoid’s back is a deployable quadcopter drone called M4, whose rotors are also capable of doubling as wheels for mobility alongside the humanoid on flat surfaces. The humanoid is capable of launching the drone directly from its own back. Although the platform is said to be hybrid, both the robot and the drone are capable of fully autonomous navigation in their respective environments. One is capable of leading the other when both are moving separately.

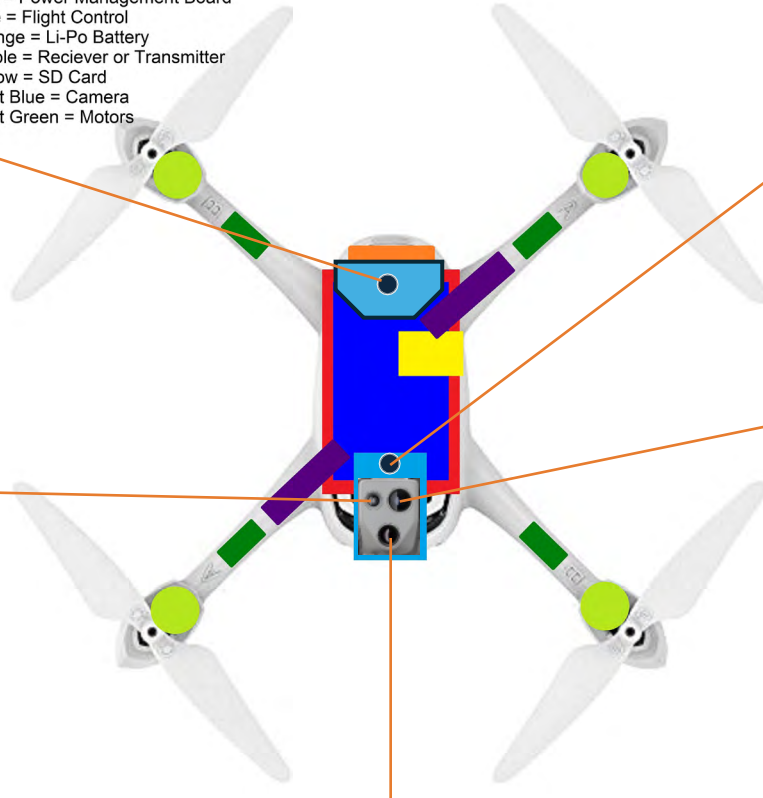
Not only is the data from the vision systems used for collision avoidance, but it’s stored locally within the humanoid for use in re-training its own internal AI. This way, if either the humanoid or the drone have encountered difficulties with any terrain or situation, it can learn how to overcome those difficulties with its next encounter.



# The Sensors that Autonomous Devices Need

## UAV Drones

**Legend:**  
 Green = E.S.C.'s  
 Red = Power Management Board  
 Blue = Flight Control  
 Orange = Li-Po Battery  
 Purple = Receiver or Transmitter  
 Yellow = SD Card  
 Light Blue = Camera  
 Light Green = Motors



### Visual Navigation System (VNS)

A VNS helps a VGR or UAV find its bearing does not necessarily have to have the highest resolution, nor does it require color. A VNS sensor often employs an active illumination technique such as low-intensity infra-red to build a 360-degree view of the drone's surroundings.

### First-person view (FPV)

High resolution is key for an FPV, along with its capability to compensate for extreme lighting conditions such as direct sunlight and pitch darkness.

### Depth sensor

Used in combination with lasers, image sensors become depth sensors, capable of deducing more information from the calculated phases of reflected light than a sensor can by itself.

### Telephoto

The zoom capacity of a telephoto lens must either be addressable remotely, or from the drone's ECU automatically.

### Thermal / infrared and near-infrared (NIR)

Light frequencies in the infrared side of the spectrum penetrate into areas where visible light would be reflected or bounced off. IR light is less susceptible to the effects of over-intensity and under-intensity, helping sensors to distinguishing objects in total fog or darkness.

*Quadcopter diagram released under Creative Commons.*

# The Sensors that Autonomous Devices Need

## VGR Robots

### Laser scanners [2x]

Additional lasers along the sides can keep the robot traveling within a set lane, or keep it from sideswiping objects along the side.

### Edge detection sensors

These are vision sensors specifically trained to recognize markings and codes along the floor and/or walls, to guide the VGR in its limited-mobility environment.



### Laser scanner

A single laser pointed directly at the floor beneath the robot can keep it centered along a set path.

### 3D depth sensors [2x]

As many as two on-board CMOS depth sensors may be used to assemble a heat map from mono images, giving the VGR a clearer sense of the path in front of it.

### 2D LiDAR

Using direct time-of-flight (dToF) to infer the quantity of reflected photons from nearby objects, quantifying those photons into time bins per interval, a LiDAR system can assemble an internal picture of which objects are in the immediate vicinity, and how fast they're coming close.

## How to Judge an Image Sensor's Quality

### Imaging performance

When assessing the right image sensor for a task, your performance criteria will be dependent upon your drone's or robot's deployment scenario. Lighting conditions are extremely different indoors from outdoors. Accounting for objects in motion will be imperative. Commercial photographers have ways to adjust shutter speed and lens apertures to achieve the aesthetic effect they're looking for. But mapping, surveillance, and scientific observation all require different characteristics from their imaging devices, especially how they utilize their native shutters.

Environmental temperature has an oversized impact on the performance of an imaging device, including on how much power it receives. Image sensors are very sensitive to heat, and at high operating temperatures, without the proper designs to compensate, image quality can become noisy.

### Product and system parameters

In addition to the typical factors such as size and cost, reliable use of power is critical. Especially for multi-camera systems such as the typical modern drone gimbal or humanoid robot "head," imaging devices need to be interoperable. They're all being managed by an electronic network, so their bandwidth levels will need to be optimized. Overallocation of bandwidth can be as great a problem as overutilization. Integrating as many functions as possible within the sensor, will aid in optimization.

### Tools and support

The finest image sensor produced today would be ineffective in a component that lacks the best available optics, a high-bandwidth interface, and a capable processor serving as its ECU. All imaging devices, like all electronic components made and sold for any purpose, must be part of a cohesive platform. onsemi collaborates with its imaging ecosystem partners to ensure that platforms, even if from multiple vendors, deliver the best functionality without hassle and without compromise.

## The Critical Importance of High Dynamic Range



8 MP sensor without HDR



8 MP sensor with HDR

*Dynamic range* refers to a sensor's ability to capture a wide range of brightness levels in a scene, from the darkest shadows to the brightest highlights. When designing an imaging system to compensate for higher illumination conditions while preserving low light and contrast, you typically have three options along different domains:

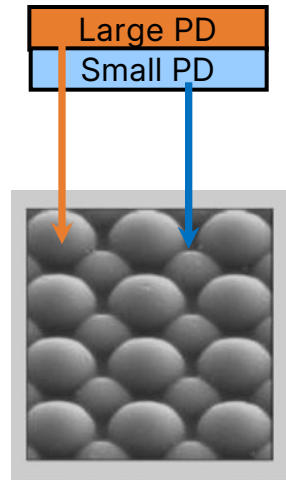
**Spatial** — Reducing the size of the photo diode, or splitting diode sizes between larger, high-sensitivity pixels and smaller, low-sensitivity, adjacent sub-pixels, to collect less light overall (which reduces signal).

**Time** — Acquiring multiple simultaneous images at different exposure levels, then compressing the time interval during which these components are integrated together (which also reduces signal).

**Gain** — Increase the amount of capacitance for data the image sensor can read and that can be stored, often by increasing diode size and adding capacitors (which increases signal but consumes memory and time).

## Three Approaches to Achieving Good HDR

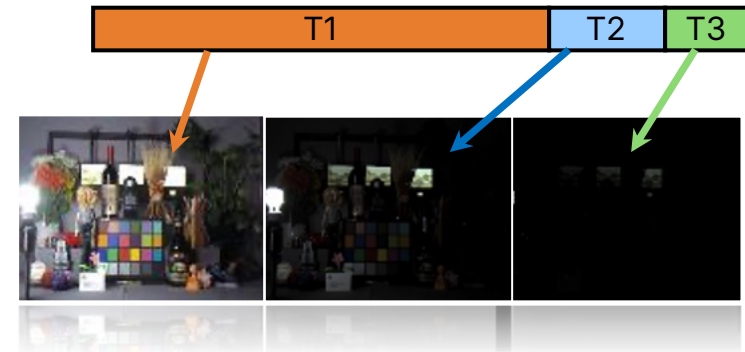
The multi-exposure approach combines three images, each with different integration times, that are mathematically combined to produce a single HDR image. One problem with this approach is that each image may be captured at different times, leading to motion artifacts. If the light source from the captured image is pulsed – for instance, from an LED or an automotive taillight – a short integration time could lead to flicker artifacts. The multi-exposure approach can become cumbersome — and even generate heat — with higher-resolution sensors. Whenever time is compressed, motion artifacts become more likely, especially when light sources are LED-based, flickering more rapidly than the human eye can detect, but not more rapidly than the shutter.



### Split-diode pixel

With the split-diode approach, the gains for larger and smaller pixels may be adjusted separately, enabling more light to be captured by one set of pixels than the other. However, the quantum efficiency differences between both sets, once integrated, can introduce color artifacts.

### Multi-exposure



### Super-exposure

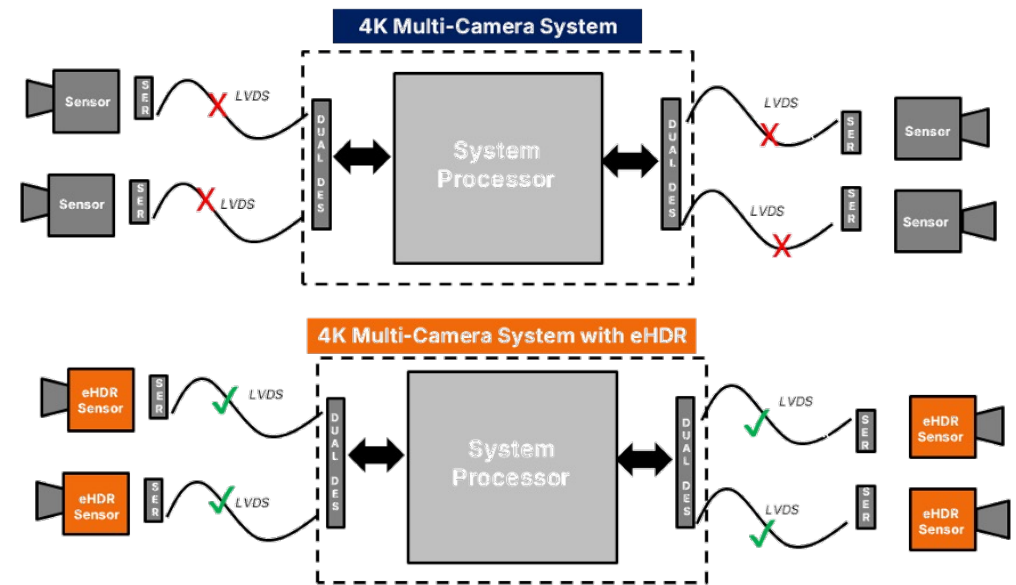


**onsemi's super-exposure** approach uses a single photodiode to capture all the information during a single integration period. At the same time, using *in-pixel multiple gain*, it achieves a low noise floor with an extremely large *full well charge* (high capacity before becoming saturated).

## The Advantages of Embedded HDR (eHDR)

High dynamic range may be achieved by relying upon the processing functions of the image sensor’s adjacent ECU, or by embedding algorithms into the sensor itself. When you use a high-resolution sensor, and you choose to implement HDR on the processor — especially with the multi-exposure approach — you risk consuming too much bandwidth. Simple math reveals that an HDR sensor outputting at 120 dB using Low-Voltage Differential Signaling (LVDS) would require 12 Gbps of bandwidth per camera. Oftentimes, ECUs cannot keep up. Hesitations can cause irregularities in the final images, including artifacts but also fast-moving objects that may be completely missed.

onsemi Hyperlux and Hyperlux LH series image sensors reduce output bandwidth by as much as fivefold, by embedding HDR image processing functionality directly onto the image sensor’s ASIC. This frees design engineers to use lower-cost, lower-bandwidth ECUs.

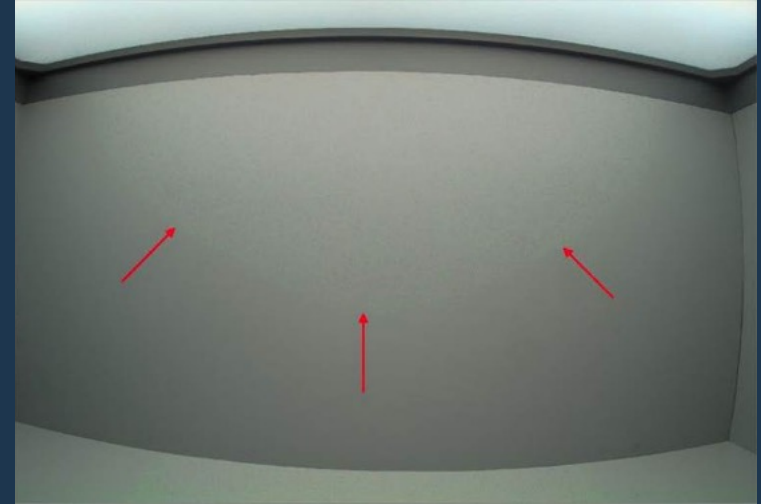


## Achieving eHDR with Intelligent Linearization

The process often used to achieve high dynamic range, which involves merging multiple images into one, is called linearization. It's typically memory intensive and consumes considerable processor resources. Using conventional methods, linearization too often results in unwanted artifacts, especially when the image depicts moving, bright, usually close objects. Sometimes the transition time from a long exposure to a short exposure is to blame for the appearance of these artifacts. One of the more common artifacts that may appear is a hard border between two hues that should belong to a single gradient. Such a border could be mistaken by a machine vision algorithm as a hard edge.

onsemi's *intelligent linearization* addresses this problem by dynamically calculating a signal for transitioning from long to short exposure, timed to achieve the smoothest transition. Smoother exposure time transitions make for smoother images with fewer artifacts. onsemi Hyperlux LH image sensors models AR0246 and AR0822 leverage intelligent linearization for its embedded HDR (eHDR) technology, achieving maximum bit depth with minimal resources.

OFF



ON

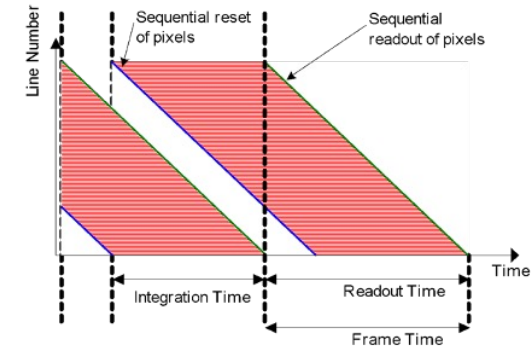


## How a Global Shutter Reduces Motion Artifacts

In a consumer-grade DSLR digital camera or a fixed-in-place security camera, a *rolling shutter* enables light to be exposed to the image sensor a portion at a time. The exposure sweeps from one side of the sensor to the other, with pixels on the already exposed portions being processed concurrently while other portions further down are just being exposed. It's a way for a camera to coordinate its imaging operations, especially at very high resolutions, to avoid buffering too much of an image in memory prior to processing even beginning.

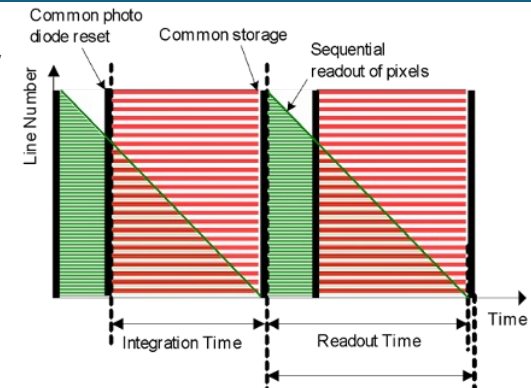
It's a clever technique for a consumer-grade camera, even if it ends up producing images whose realism ends up being slightly distorted, especially when capturing objects in fast motion. For an imaging device being used for drone or robot navigation, or for capturing a scene that can be used to detect the identity of objects within that scene, a rolling shutter is inefficient.

A *global shutter* eliminates the illusion of moving objects appearing to have distorted shapes. All regions of an image are captured at once by the entire photodiode, before the pixel values are stored in memory.



Rolling shutter

## Global shutter

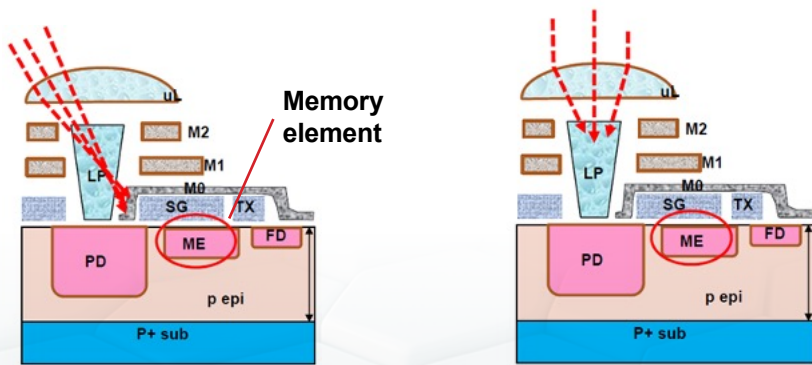


## Accounting for Parasitic Light Sensitivity with GSE

To ensure that the transfer of image data from a global shutter to the memory element (in the diagrams at left, **ME**) is immediate, the ME is positioned adjacent to the photodiode. One possible adverse aspect of this design choice is that the ME may be affected by *incident light* or *parasitic light* that may escape the light pipe (**LP**).

One effect of parasitic light is visible from these photos, which show the ghost-like apparition of business cards taped to moving fan blades. Here, light from subsequent exposures is superimposed on previous ones, resulting in an illusion of transparency.

When an image sensor utilizes mitigation methods for *global shutter efficiency (GSE)*, it can ensure that captured images of fast-moving objects remain crisply-defined and artifact-free. Hyperlux SG sensor models AR0145 and AR0235 from onsemi achieves twofold increases in overall GSE, optimizing for accurate and fast capture of moving scenes at 120 fps. The results are clear, low-noise images in both dim and bright lighting conditions. Hyperlux SG sensors feature auto-exposure control, auto black-level correction, windowing, skipping, and pixel binning — combining data from four pixels into one.



Tilted incident light

Properly focused light

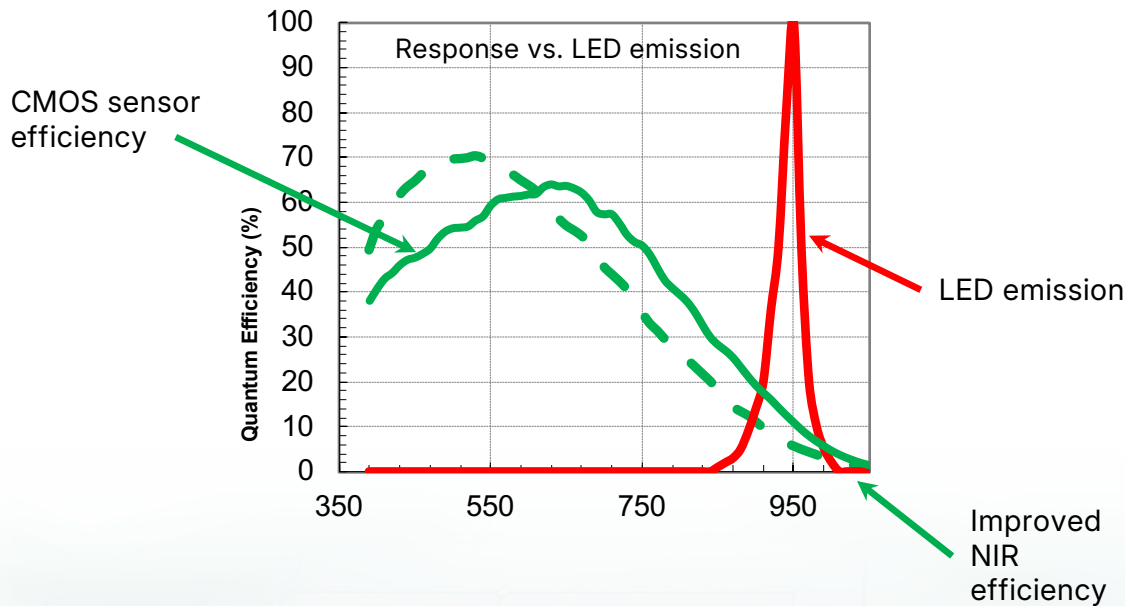


High Global Shutter Efficiency

## How Near-Infrared (NIR) Lighting Improves Accuracy

An image sensor optimized for infrared (IR) frequencies often utilizes active illumination. It “lights up” the object in front of it using IR or near-infrared (NIR) LEDs, or using Vertical Cavity Surface-Emitting Lasers (VCSEL). In either case, IR light will be emitted in very short pulses.

For an IR or NIR sensor to capture the reflected light from those pulses, its timing must be in close alignment with the pulses’ timing. The GSE of an IR sensor is greatly improved when it’s engineered for optimum response from all of its pixels, at exactly the moment of the IR emitter pulse.



Sunglasses in ambient light



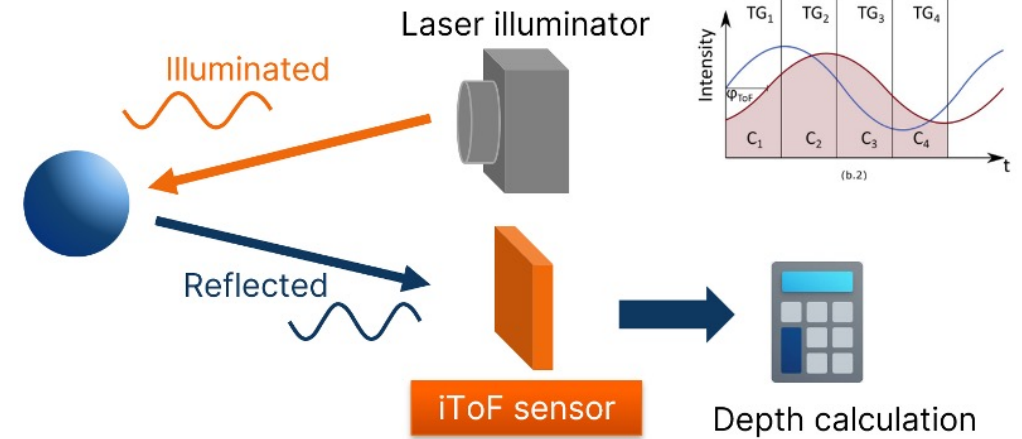
Sunglasses with 940 nm IR LEDs

## Enabling Indirect Time-of-Flight (iToF) with CMOS Sensors

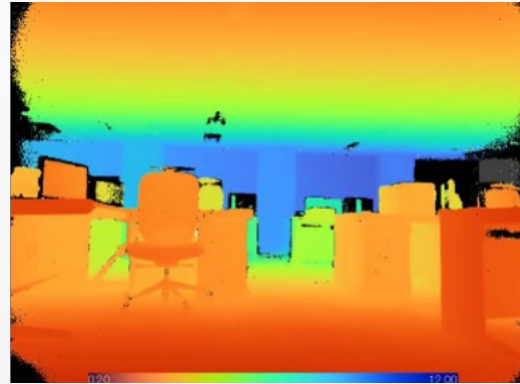
Distance is a one-dimensional concept that can be embodied by a single line. For depth perception to be achieved using two-dimensional images, an image processor needs at least two simultaneous images from different points. How accurately the processing mechanism can estimate depth depends in large measure upon the resolution of the sensors for both images.

Because resolution is always a limitation, CMOS-based image sensors such as onsemi Hyperlux ID have limited ranges of depth perception. For robots and drones to perceive depth beyond their limits, they need to employ a technique called *indirect time-of-flight* (iToF). Using its global shutter coupled with a 940 nm infrared laser diode as its illuminator, **onsemi Hyperlux ID** captures eight simultaneous exposures (four phases at two frequencies each), and then stores the data from those exposures together as a single captured frame. This reduces motion-induced phase errors to the point of near-elimination.

**Hyperlux ID model AF0130** contains an embedded depth-processing ASIC that handles all its depth perception arithmetic on-board. For instance, when light from a constant modulating source such as a laser is reflected by an object, the echoed light will be slightly out of phase. Simple trigonometry gives the ASIC an easy way to infer a single distance value (the “indirect” part of “iToF”) from the phase shifts for all four pairs of exposures.



## Leveraging iToF for Greater Depth Perception

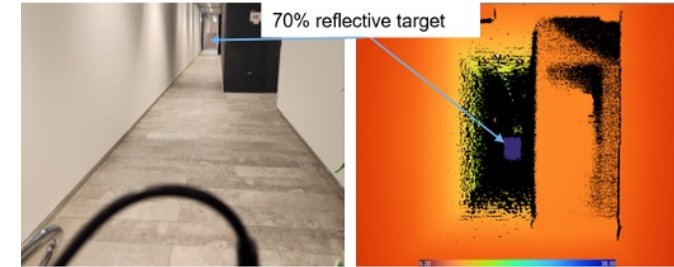


Depth Map

The reflectivity of an object is another way of expressing the strength of the light signal produced by that object. Visualization software enables relative depth to be represented chromatically using a depth map. Here, nearer objects are represented by the redder portion of the spectrum, further objects on the opposite end toward blue-violet.

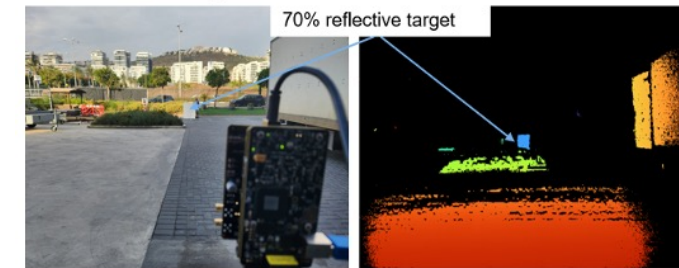
Many AMRs and robots today use VCSEL lasers as their principal active illumination components. Here, the image sensor should be capable of calculating phase shifts of the returning light frequencies from both the VCSEL and its own NIR, in so doing modulating the intensities of both frequencies.

30m, indoors



Depth Map

20m outdoors, ~20KLux



Depth Map

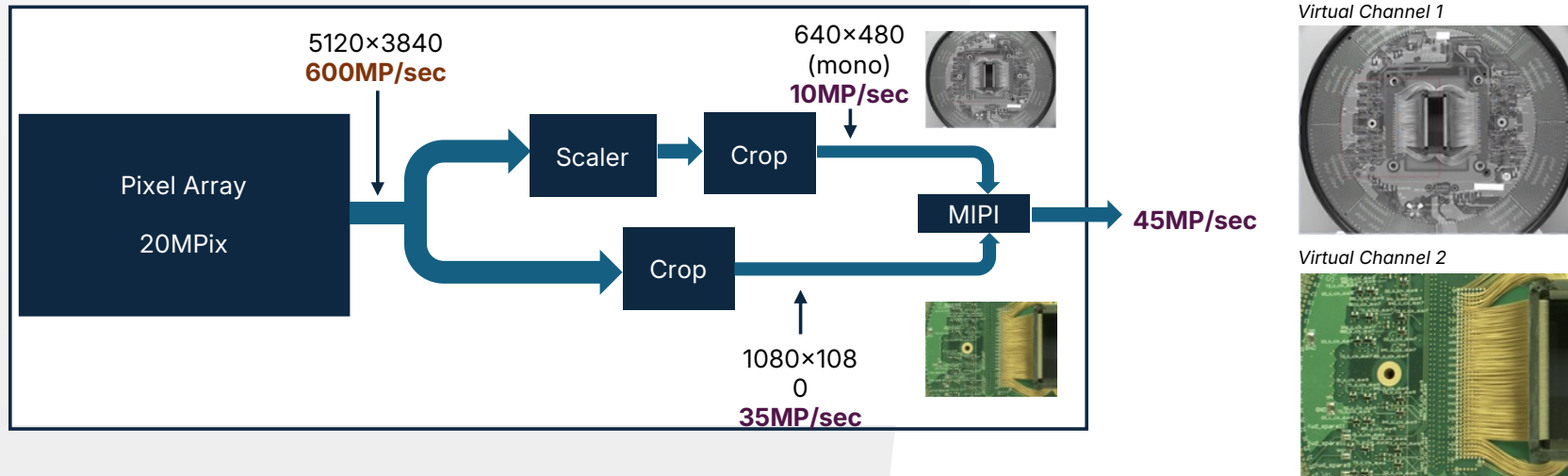
In real-world simulations conducted by onsemi engineers, when using a VCSEL, Hyperlux ID AF0130 was able to clearly record 70% reflective target at 30 meters under fluorescent light in a light, neutral-colored hallway, and at 20 meters in the shade on a hazy day under 20,000 lux of illumination.

## Integrating Smart Region-of-Interest (ROI) Functionality

There are times when a manufacturing robot needs the electronic equivalent of a bifocal lens. It needs to be able to see the broader space, plus the fine detail of a specific element, simultaneously.

onsemi Hyperlux LP model AR2020 supports a maximum resolution of 20 megapixels (MP) at 60 frames per second (fps). It's capable of subdividing its own frame to isolate and maximize detail for one zoomed-in region, alongside the complete capture range at native resolution.

For any system designed to capture two frames to generate separate levels of detail, latencies between the capture times of both frames could cause the image processor to miss important details. onsemi's smart region-of-interest functionality (SmartROI) enables AR2020 to replace machine vision systems that utilize dual sensors trained on the same region at different magnifications. For an articulated robot tasked with pick-and-place operations, SmartROI can enable it to perceive the entire scene in front of it, while simultaneously focusing on the object it needs to move and the location where it's moved to.



## onsemi Hyperlux Solutions

### First Person View (FPV)

The best-suited, most practically priced image sensors for FPV operation utilize rolling shutters, often incorporating *global reset release* (GRR) to help simulate more of the conditions of a global exposure. In these tables, “ERS” refers to *electronic rolling shutter*, but “GRR” is added for models that support this method of reducing artifacts.

With *rolling shutter readout*, AR2020 increases quantum efficiency and reduces readout noise without introducing distortion. AR2020 also supports wake-on motion (WoM) technology, which enables the sensor to operate on an ultra-low

power mode, consuming just 1/100 of normal power until variations are detected in a scene with just 16 × 9 sensor resolution.

The Scaler, as indicated in these tables, refers to the ability to use a so-called *Bayer filter* to subsample images mathematically to produce a smaller, yet still accurate, image (notice “Subsampling modes” are also accounted for in these tables). For sensors with global shutters, when the shutter is focused on far distances and a near object comes into frame, *dynamic context switching* enables the sensor to reset itself immediately, so that the near object isn’t just a massive blur.

Model	Resolution	Pixel size (µm)	Optical format	Shutter type	Max. FPS	Max. dynamic range	Scaler	SmartROI	Context switching	Sub-sampling modes
AR2020	5120 x 3840	1.4 / 2.0	1/1.8"	ERS/GRR	60	73 dB (eDR 1-exp) 100 dB (LI-HDR)	✓	✓	Up to 7	✓
AR0822	3840 x 2160	2	1/1.8"	ERS/GRR	60	120dB eHDR	✗	✗	Up to 7	✓

## onsemi Hyperlux Solutions

### Visual Navigation Systems (VNS)

For collision avoidance, it's best for an image sensor to use a rolling shutter with HDR and maximum speed. Models AR0821 and AR0822 are especially well-suited for this task on account of their support of GRR. For operations

such as Q-code and barcode reading, AR0145 and AR0235 are better adapted because of their global shutter and high frame rates, ensuring against image distortions.

Model	Resolution	Pixel size (µm)	Optical format	Shutter type	Max. FPS	Max. dynamic range	Scaler	SmartROI	Context switching	Sub-sampling modes
AR0144	1280 x 800	3	1/4"	Global	60	72 dB	X	X	Up to 4	✓
AR0145	1280 x 800	3	1/4.3"	Global	120	65 dB	X	X	Up to 4	✓
AR0234	1920 x 1200	3	1/2.6"	Global	120	72 dB	X	X	Up to 4	✓
AR0235	1920 x 1200	2.8	1/2.8"	Global	230	65 dB	X	X	Up to 4	✓
AR0246	1920 x 1080	2	1/4"	ERS/GRR	60	120dB (with ALTM)	X	X	Up to 7	✓
AR0341	2312 x 1746	2.1	1/3.2"	ERS	60	110dB (1-exp), 150dB (3-exp)	X	X	Up to 7	✓
AR0821	3848 x 2168	2.1	1/1.7"	ERS/GRR	60	Up to 140+dB	X	X	Up to 7	✓
AR0822	3840 x 2160	2	1/4"	ERS/GRR	60	120dB eHDR	X	X	Up to 7	✓

## onsemi Hyperlux Solutions

### Depth sensors

onsemi's Hyperlux ID AF0130 and AF0131 depth sensors deliver results that can transform the design of UAVs and VGRs, making them easier to build, easier to maintain, simpler to engineer and develop, and easier to afford.

- ▶ **AF013x's 1.2 MP BSI global shutter mechanism** enables the most accurate depth perception capability possible from a CMOS image sensor
- ▶ **Smart iToF with on-chip storage** (AF0130 only) reduces, or even eliminates, motion artifacts, increasing the accuracy of AI software that requires accurate machine vision for image and object recognition systems

- ▶ **Integrated on-chip algorithmic processing** completely eliminates the need for external microcontrollers, which in turn simplifies and shrinks component design while reducing power requirements
- ▶ **Maximized ambient light rejection** improves unambiguous range, enabling a wider array of new machine vision applications
- ▶ **Open software development and programmability** with customizable contexts using **onsemi's industry standard DevWare X environment**



onsemi  
Hyperlux AF0130

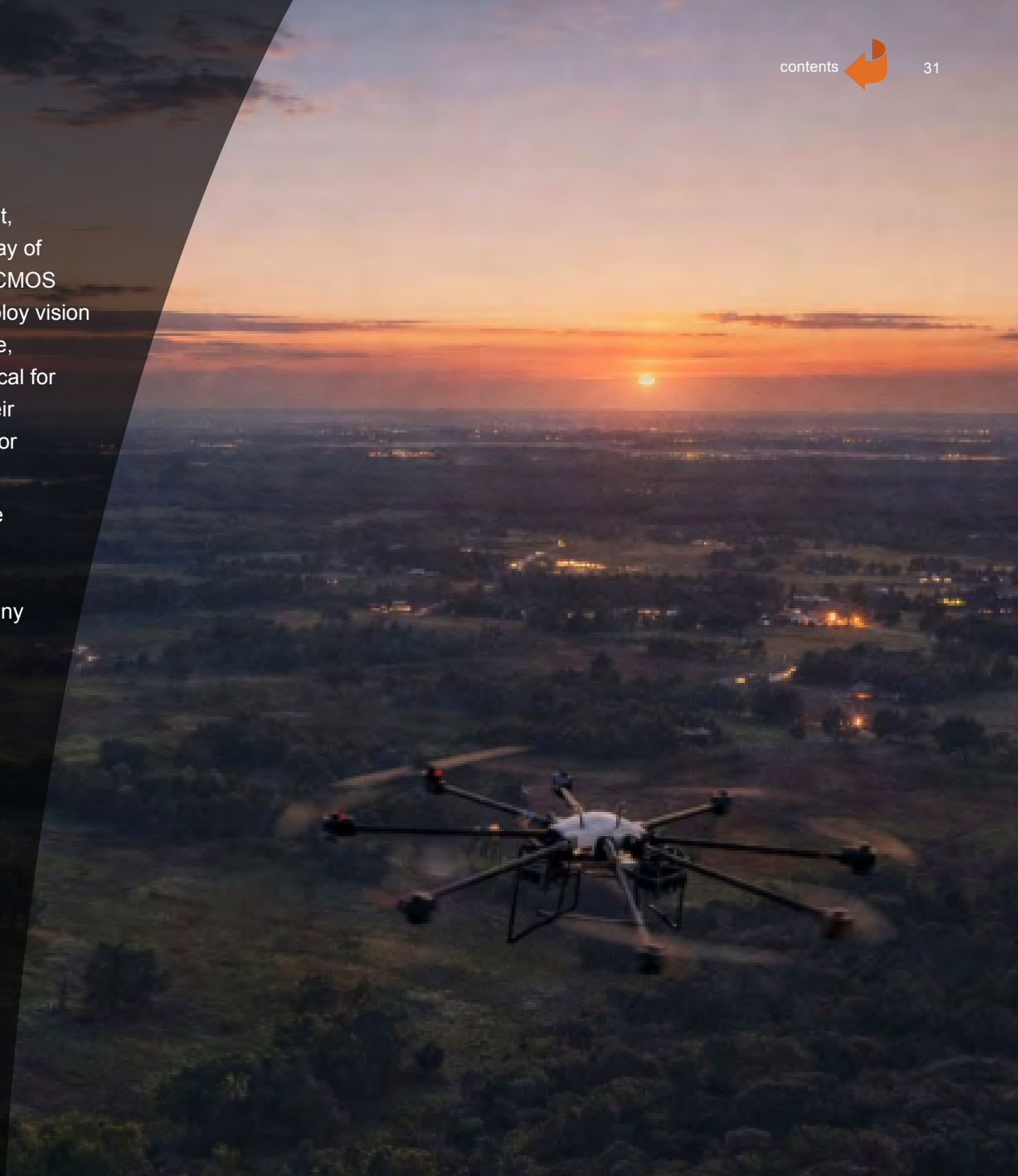
Model	Resolution	Pixel size (µm)	Optical format	Shutter type	Max. FPS	Max. dynamic range	Scaler	SmartROI	Context switching	Sub-sampling modes
AF0130	1280 x 960	3.5	1/3.2"	Global	60	67 dB	X	X	Up to 64	✓
AF0131	1280 x 960	3.5	1/3.2"	Global	60	67 dB	X	X	Up to 64	✓

## Expanding Perception for Our World

Robotics has become an exciting technology again for two reasons: First, networking has connected robots — even wirelessly — to a limitless array of storage and a reliable source of monitoring and maintenance. Second, CMOS imaging technology has made it feasible to easily and inexpensively deploy vision and depth sensing capability anywhere on the robot where it needs to be, such as the furthest extremity of its arms. It's not just feasible, but practical for aircraft designers to distributed image and depth sensors throughout their designs. Vision has emboldened the UAV and VGR industries with a vigor not seen since the 1960s.

onsemi technology makes it practical for autonomous mechanisms to be equipped with imaging capabilities that extend beyond their “heads” and their gimbals. Now, the applications under development — or just under consideration — for robots and drones will no longer be constrained in any way by their inability to see what they're doing and where they're going.

Learn more from [onsemi.com/hyperlux](https://onsemi.com/hyperlux)





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for more information and  
additional resources.

