Increasing Object Recognition Accuracy with Low Bandwidth High Dynamic Range (eHDR)

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Prepared by: Jason Wang and Raviteja Akella
onsemi

Image-based artificial intelligence (AI) is a crucial technology for enabling advanced automotive, surveillance, and industrial mobile robot applications. The ability to accurately detect and identify objects is essential for implementing advanced capabilities that make these systems more autonomous.

One of the significant challenges with improving upon existing object detection and identification technology is increasing accuracy under different lighting conditions and over a greater distance. For example, the backup camera of an automobile needs to be able to operate accurately in situations such as a dark underground parking lot with glaring headlights from other vehicles and along a bright street partially shaded by buildings. Similarly, a surveillance system must be able to distinguish between the movement of an unauthorized person and an animal as they move in the shadows or bright areas to determine whether to trigger an alarm accurately.

Industrial mobile robots, engineers in a work cell have more control over lighting and can ensure the ideal levels of brightness where the most detail is required. Mobile robots, however, move from space to space—spaces between cells are not as controlled. In addition, the lighting within a cell may not be optimal for a mobile robot station. Thus, industrial mobile robots must also operate under various extreme lighting conditions.

Captured images require a high dynamic range to achieve greater levels of accuracy. The higher the dynamic range, the more detail an image captures, improving object detection and identification accuracy. Complicating design for engineers is the increased volume of image data and number of image sensors these systems must capture and process. For example, 8 to 10 cameras in a car are commonly installed for ADAS function.

This white paper will explore how using multiple images can increase dynamic range and how to overcome some challenges associated with implementing higher dynamic range in embedded applications.

High Dynamic Range

The dynamic range of an image sensor defines the capacity for the sensor to capture detail in both the darkest and brightest areas of an image. Figure 1 shows a photo taken with a shorter exposure time. The resulting image captures detail in bright areas of the image but loses detail in the dark spots because of underexposure.

Figure 1. Image with Shorter Exposure Time Captures Detail in the Bright Areas and Loses Detail in the Dark

Figure 2 shows an image taken with a longer exposure time. In this case, the resulting image captures detail in dark areas of the image but loses detail in the bright spots because of overexposure.

Figure 2. Image with Longer Exposure Time Captures Detail in Dark Areas and Loses Detail in Light Areas

Figures 1 and 2 illustrate the dynamic range issues encountered in autonomous vehicles, surveillance, and mobile robot applications. When the scene contains dark and bright areas, there will be a loss of detail depending on the use of short or long exposure. Images must balance the available encoding bits between bright and dark to achieve superior identification capabilities.

Multiple Exposures = Higher Dynamic Range

One method for increasing the dynamic range of a photo is to capture multiple images at different exposure rates and then combine them. This gives the recognition system a more comprehensive range of light and detail to work with.

Today's image sensors typically capture images with a dynamic range of between 60 dB to 78 dB (i.e., a single exposure). To put this in context, the human eye can see with more than 100 dB. Combining two images with different exposures will generate a dynamic range of 96 dB, three exposures can achieve 120 dB. Thus, at least three exposures are required to see as well as a person.

Figure 3 shows how a sensor can be connected to an image signal processor (ISP) to create a high dynamic range (HDR) image. In this example, the sensor captures three images with different exposures. The sensor handles analog processing, ADC conversion, and digital corrections to prepare the images to be passed to the ISP—called line interleaving because of the interleaving of the different exposure−rate images when sent to the ISP. For example, if using three images, the exposure pattern will be long, medium, short followed by long, medium, short. The photos are serialized and sent over a standard interface, such as Mobile Industry Processor Interface (MIPI), to the ISP. The ISP separates and combines the images into a high dynamic range 20−bit image for final linear image processing.

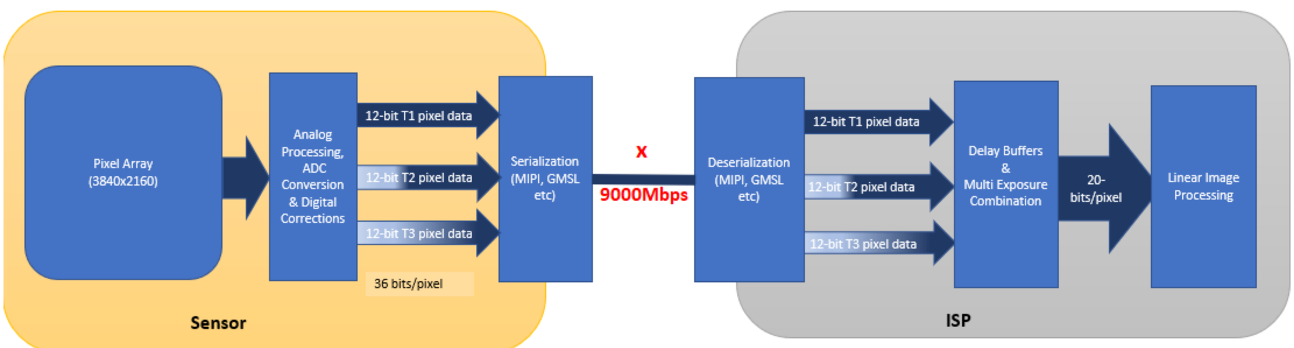

Figure 3. A Typical High Dynamic Range Architecture Sends Multiple Images over the Interface between the Image Sensor and ISP, potentially Straining or Exceeding the Available Bandwidth at High Resolutions

The 4K Challenge

Part of the challenge with this approach is that using multiple images requires more bandwidth. Bandwidth has become a significant design concern with increasing camera resolution, and as cameras move to 4K resolution, the memory needed per image increases. As shown in Figure 3, the bandwidth required to send three 4K images is 9000 Mbps, potentially straining or exceeding the available bandwidth of serializer system for long distance receivers. (Note: Bandwidth calculations are based on 30 fps)

The MIPI Alliance is working on increasing its interface data rates. However, this will likely lead to higher component costs and limit an OEM's ISP options. Furthermore, operating a high–speed interface increases power consumption compared to a slower interface. Finally, a significant part of the ISP's processing capacity must be dedicated to receiving and combining multiple images.

An ideal approach would be to offload part of the processing burden from the ISP to the image sensor—known as Embedded High Dynamic Range (eHDR). Figure 4 shows an example of this approach using the AR0822 an eHDR rolling shutter CMOS digital image sensor from **onsemi**. An eHDR image sensor still captures images and performs analog processing, ADC conversion, and digital corrections to prepare the photos for combining. However, the high dynamic range capabilities of the AR0822 enable it to capture up to four pictures with different exposure times and combine them into a 20–bit high dynamic range image, just like an ISP. The image is companded: compressed to 12–bit before being serialized, sent to the ISP, and decompressed. Companding is a non–linear technique representing high dynamic range bit depth without losing significant fidelity. The ISP receives the compressed image, decompresses it into a 20–bit image, and proceeds to final linear image processing.

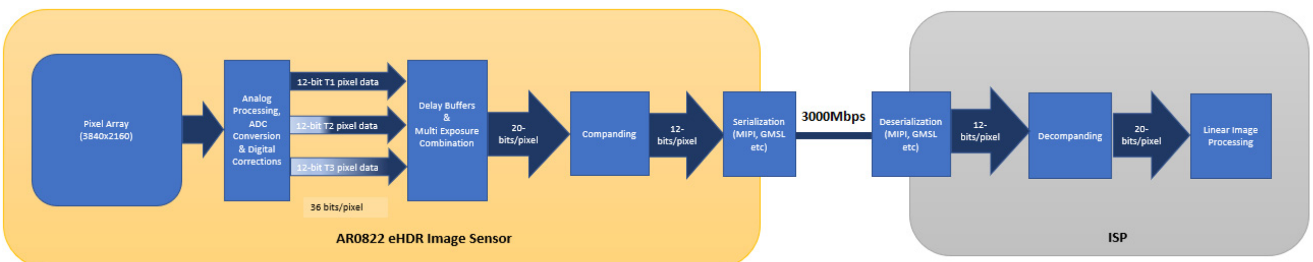

Figure 4. An AR0822 Embedded High Dynamic Range (eHDR) Image Sensor

As shown in Figure 4, there are many advantages to eHDR, including bandwidth is conserved. A 4K eHDR architecture requires only 3000 Mbps bandwidth, well within the capabilities of current ISPs, keeping both component cost and power consumption down. In addition, if a general–purpose processor performs image signal processing rather than an ISP, the eHDR will provide superior performance and power efficiency.

Figure 5 shows the difference in eHDR bandwidth for one, two, three, and four exposures. Since the bandwidth is the same for an eHDR image sensor with one to four images, OEMs can select the optimal number of exposures to achieve the desired dynamic range without impacting bandwidth or additional loading on the ISP. Thus, the higher the accuracy needed, the greater the bandwidth and ISP processing savings.

For many applications, bandwidth savings translate to BOM savings in wire infrastructure. For example, the lower bandwidth of an eHDR–based design could enable OEMs to continue to use the existing wire harness while improving recognition accuracy. Similarly, surveillance applications could connect more cameras providing greater detail using existing wiring.

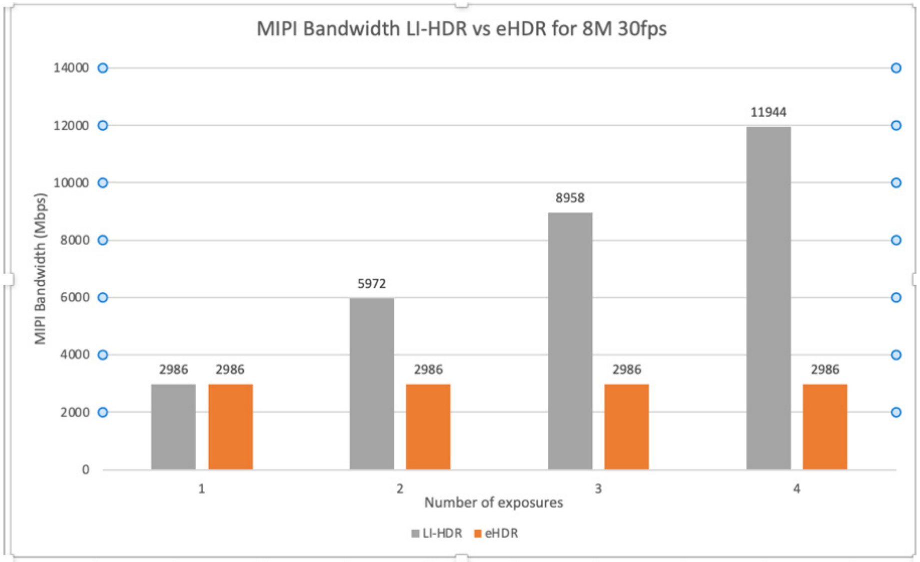

Figure 5. Traditional HDR Uses Greater Bandwidth Based on the Required Exposures

For existing 4K designs, the system can introduce a high dynamic range using multiple exposures to increase object detection and identification accuracy without significantly loading the ISP. For solutions looking to upgrade to 4K, offloading processing to an eHDR image sensor keeps designs simple, cost−effective, and power efficient.

In general, offloading the processing enables a more extensive range of ISP to support a higher dynamic range, giving OEMs a wider choice of ISP options they can consider. Alternatively, high−performance ISPs can support multiple eHDR sensor inputs, simplifying designs by reducing the overall number of ISPs required. Being able to handle numerous sensors also makes features like panorama capabilities possible because a single ISP can now build a 360° view with high dynamic range.

Another benefit of keeping bandwidth down is that OEMs have the option to use a serializer to transmit raw sensor data throughout the system. Standards like MIPI and Gigabit Miltimedia Serial Link (GMSL) are for short distances, and with a serial interface, camera modules can be further away from the ISP. This is especially useful for applications like carDVR and industrial mobile robots, where four cameras on all sides of the system give the driver or robotic controller a complete surround view (see Figure 6) with a high level of detail.

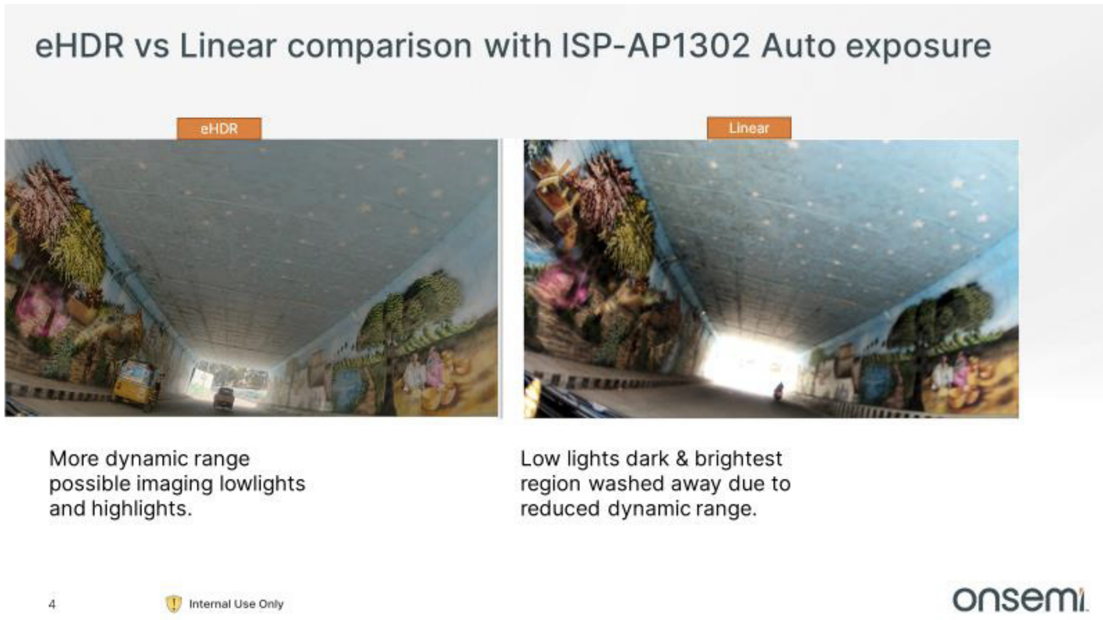

Figure 6. eHDR vs. Linear Comparison with ISP−AP1302 Auto Exposure

Integrated Capabilities

Because the multiple exposures are taken at different times, this introduces certain artifacts that must be addressed. For example, moving objects will be in slightly different places among the multiple exposures. Another artifact is LED flicker. LEDs conserve energy by operating with a duty cycle where the LED turns on and off at a frequency that, while not noticed by the human eye, can be seen by a camera. Thus, because the LED might be off during the first exposure and on during the second, there will be different lighting levels among the images in scenes with LED lighting.

Processing techniques are available to mitigate and minimize the effects of these artifacts, including motion compensation and LED flicker reduction. With a traditional ISP approach, such processing must be handled by the ISP, increasing its load. Integrating processing, such as motion compensation and LED flicker reduction, into the eHDR image sensor optimizes the system for performance and power. Integration simplifies design because engineers don’t need to develop and implement such processing.

eHDR image sensors also integrate advanced capabilities to optimize bandwidth and power consumption, including in−pixel binning, windowing, and summing. Video and single frame mode support provide flexible region of interest (ROI) capability.

As object detection and identification technology continue to evolve, increasing accuracy requirements combined with support for more cameras with more excellent image resolution, such as 4K, are putting a strain on the interface between the image sensor and ISP.

An eHDR approach to increasing recognition accuracy in automotive, surveillance, and industrial mobile robot applications ensures high−quality performance in low−light and other challenging lighting conditions. Today’s eHDR image sensors can work with up to four exposures, delivering more than 140 dB for applications that need the highest accuracy. With integrated processing capabilities, eHDR image sensors reduce the strain on interface bandwidth, offload image signal processors, and potentially lower wiring costs while increasing power efficiency and the accuracy of object detection and identification in autonomous systems.

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