CELEBRATING 20 YEARS OF CAMERA ENGINEERING

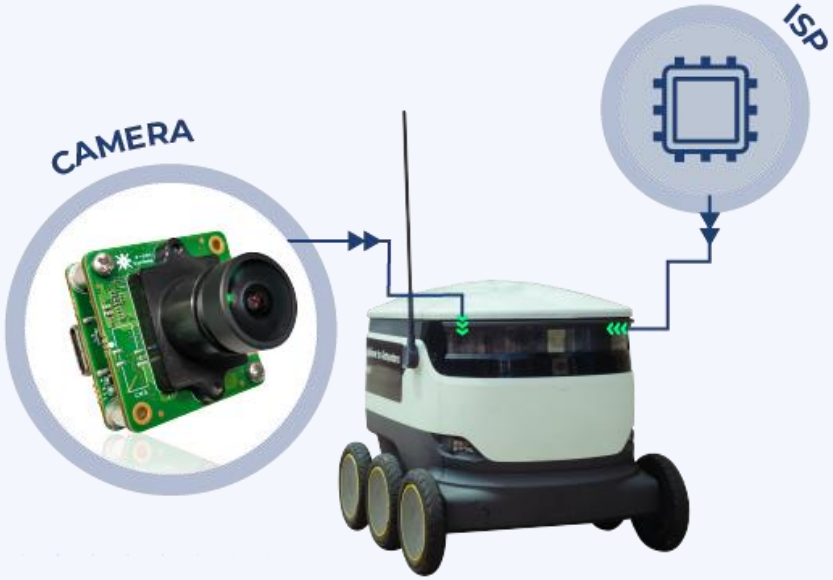
e-con Systems™
Think Camera. Think e-con.

MASTERING IMAGE QUALITY :

The Power of Imaging Signal Processors in Embedded Vision

Suresh Madhu
Head of Product Marketing
e-con Systems

Arun Asokan
Head of the ISP Division
e-con Systems



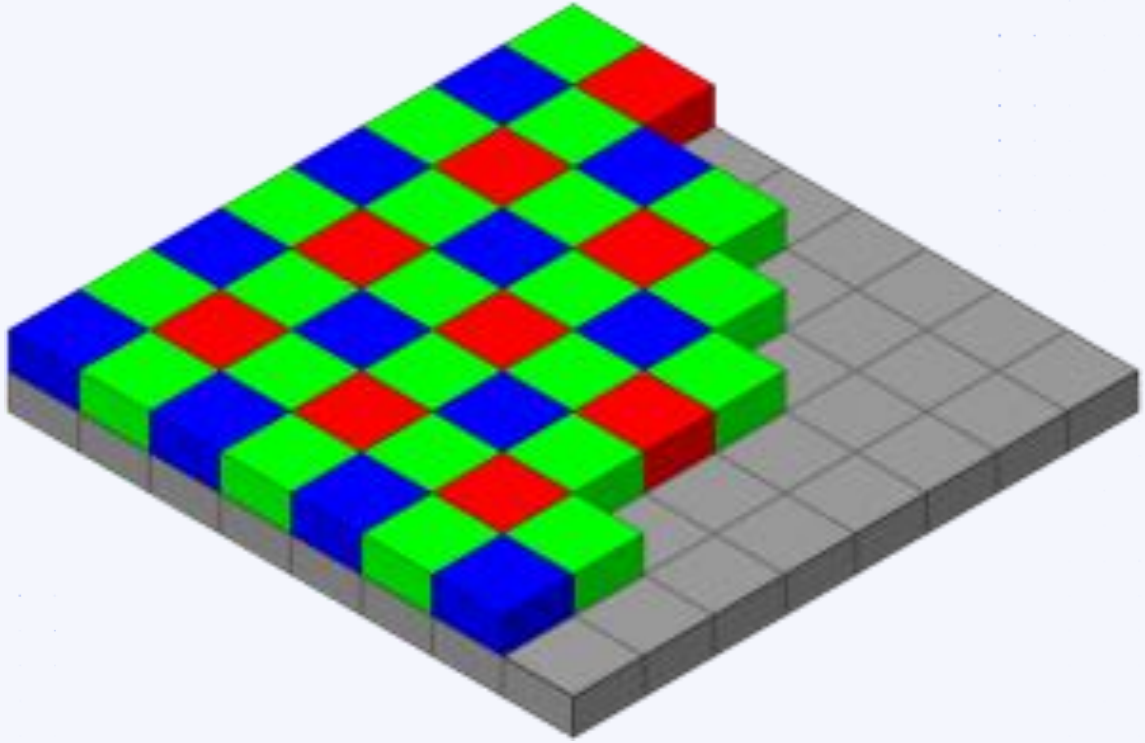
The importance of ISPs in embedded vision cameras

What Application expects from a camera?

- Understandable Image format
  - RGB888
  - RGB565
  - YUV422
  - YUV420, etc.
- Accurate Color Reproduction
  - Across all color temperatures
- Perfect Exposure
- High Dynamic Range
- Reduced Noise

What Sensor Provides?

- RAW Bayer Output
- BGGR
- GBGR
- RGBG, etc.



What Sensor Provides?

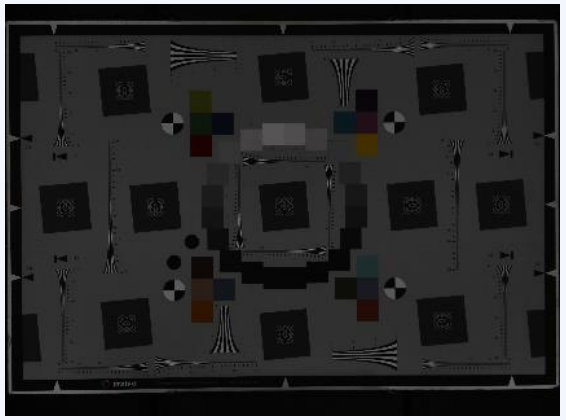
Color inaccuracies with varying color temperatures

3000K **5000K** **9000K**

What Sensor Provides?

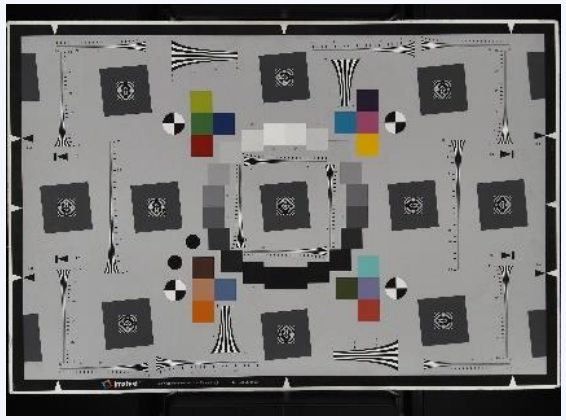
Programmed Exposure Time

30 ms



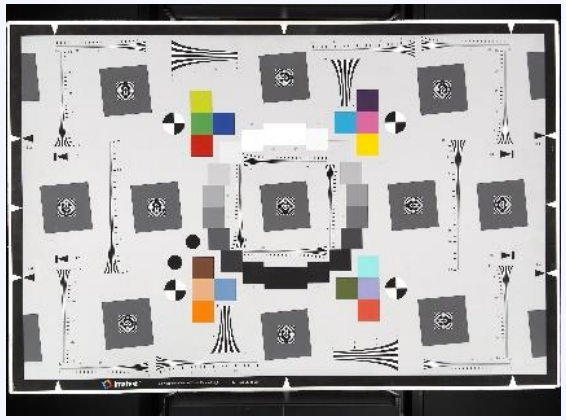
Under exposed

30 ms



Properly exposed

30 ms

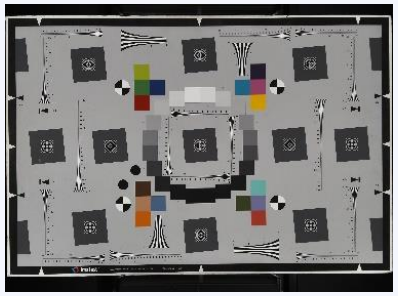


Over exposed

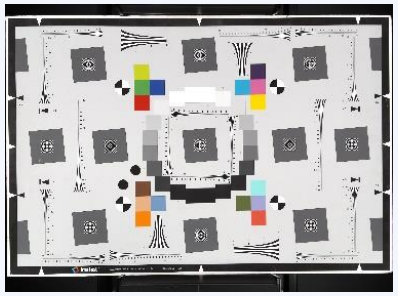
What Sensor Provides?

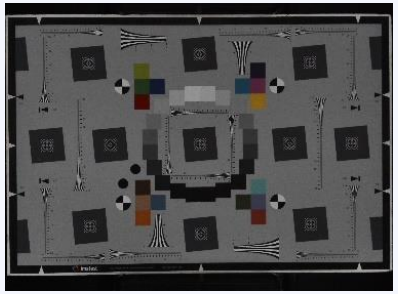
Multi frames - no HDR processing

10 ms

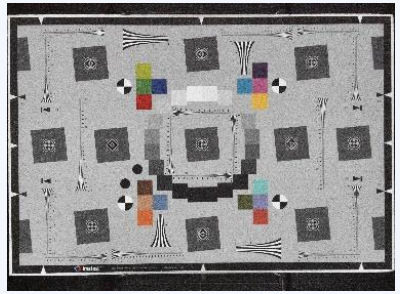


20 ms





Gain 6dB



Gain 12dB

What Sensor Provides?

Captures noise

10 lux - Noisy

What Application expects vs What Sensor provides

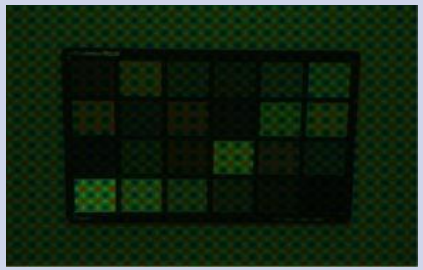
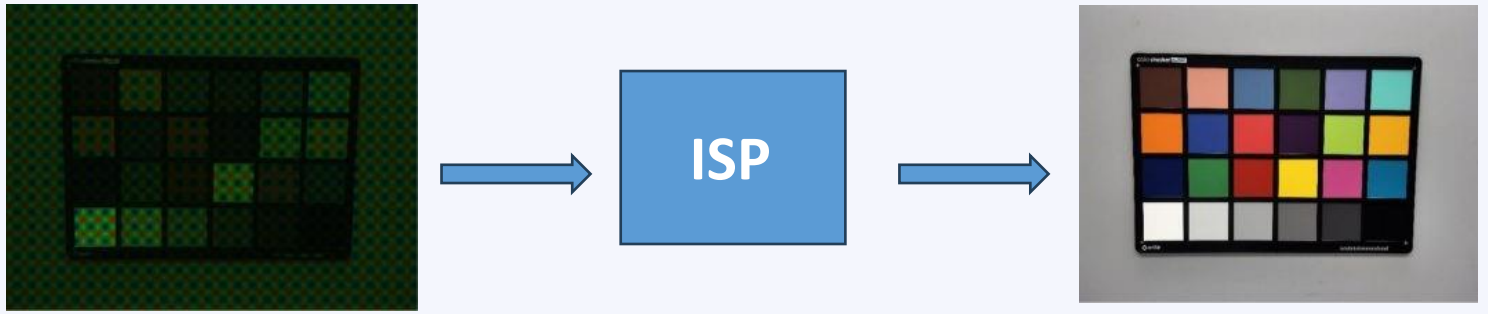
Application	Sensor
Image format that requires RGB information in each pixel	RAW Bayer Output - Only one color pixel in each pixel
Accurate Color Reproduction	Color inaccuracies with varying color temperatures
Perfect Exposure	Programmed Exposure
High Dynamic Range	Multi frames - no HDR processing
Noiseless	Captures noise
	

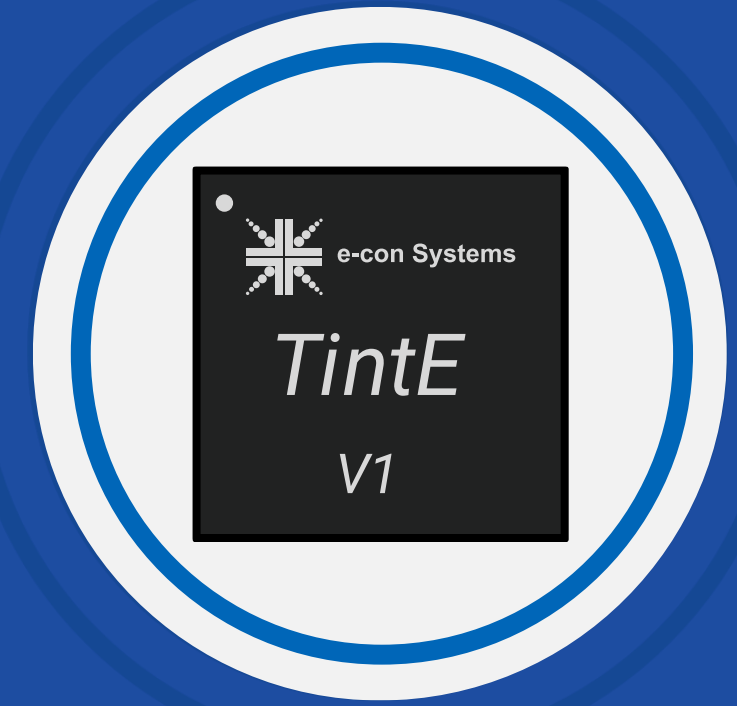
Image Signal Processor



DEBAYERING | DENOISING | AWB and Color Correction | Auto Exposure

Dead Pixel Correction | Gamma Correction | Lens shading Correction | Auto Focus | Brightness

Backlight Compensation | Contrast | Sharpness | Compression | HDR



Major types of ISPs

Types of ISPs

Standalone ISPs

- High processing power , High flexibility for customization
- Advanced image processing - detailed noise reduction, HDR, and sophisticated color processing
- Higher cost
- High impact on form factor
- No or Lower CPU/GPU load

On-sensor ISPs

- Low processing power, No flexibility
- Basic image processing
- Cost Effective
- No impact on form factor
- No or Lower CPU/GPU load

Types of ISPs

Host Processor ISPs

- Moderate processing power , No or low flexibility for customization
- Moderate image processing - detailed noise reduction, HDR, and sophisticated color processing
- Cost effective
- No impact on form factor
- Moderate CPU/GPU load

Software-based ISPs

- High flexibility
- Basic/Advanced image processing
- Cost Effective
- No impact on form factor
- High CPU/GPU load
- Potential Latency issues

Types of ISPs

ISPs Comparison

	Standalone ISPs	On-sensor ISPs	Host-based ISPs	Software based ISPs
Image Processing Capability	High	Low	Moderate	High
CPU/GPU Load	Low	Low	Moderate	High
Cost Effective	High	Moderate	Low	Low
Impact on Form Factor	High	Low	Low	Low
Latency	No	No	No	High

Parameters that define an ISP's contribution to image quality

- ✓ **What could it do?**
- ✓ **How well it does it?**

- **What could it do?**
- **How well it does it?**

  - Types of sensors supported
  - Types of IQ processing blocks supported
  - Data rate in the overall pipeline

Types of sensors supported

- Support for resolution and the data
- Support for different Color Filter Arrays (Bayer, Monochrome, and RGB-IR)
- Support for different HDR types (split pixel HDR, DOL HDR, etc.)

Types of IQ processing blocks supported

- Basic blocks - De-mosaic, color correction, lens shading correction, gamma, contrast/tone mapping, noise reduction, sharpness, scaler/resizer, etc.
- Auto blocks - 3A (Auto exposure, Auto white balance, and Autofocus)
- Advanced blocks - HDR processing, temporal noise reduction, color processing, distortion correction, etc.

Data rate in the overall pipeline

- Based on support for the data rate handled by each of these blocks
- Pipeline for video streaming or still capture to be determined
- Impacts multi-camera streaming

- What could it do?
- **How well it does it?**

✓ Color accuracy

✓ Spatial Frequency Response

✓ Signal to Noise Ratio

✓ Uniformity

✓ Dynamic Range

Color Accuracy

- Reproducing colors under different types of lighting
- Using multiple ISP blocks like de-mosaic, color correction and auto white balance blocks

Uniformity

- Maintaining uniformity of the output brightness in terms of center to the corners
- Handling lens-related brightness fall off
- Using the lens shading correction block

Signal to Noise Ratio

- Effectively retaining the signal (when compared to noise)
- Using multiple ISP blocks like noise reduction, sharpness, and temporal noise reduction

Spatial Frequency Response

- Reproducing various scene details
- Using multiple ISP blocks like de-mosaic, sharpness, and scaler

Dynamic Range

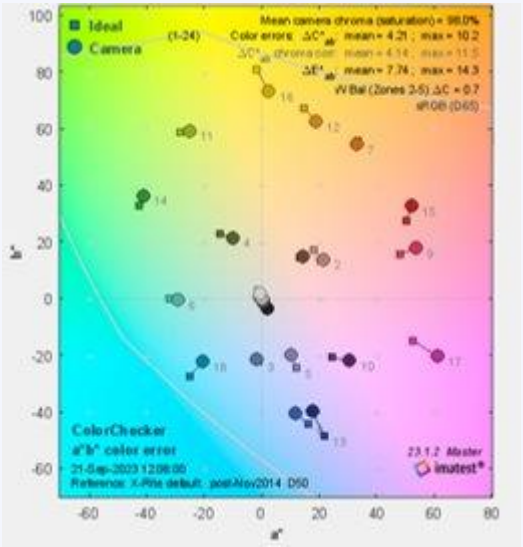
- Reproducing the brightest and darkest parts of the scene
- Bringing out the small contrast variations within these limits
- Using multiple ISP blocks like HDR processing, gamma, and contrast/tone mapping

How these blocks operate, given the ISP limitations, leads to performance differences. Limitations include memory, power consumption, speed, and algorithms.

e-con camera IQ report (reference)

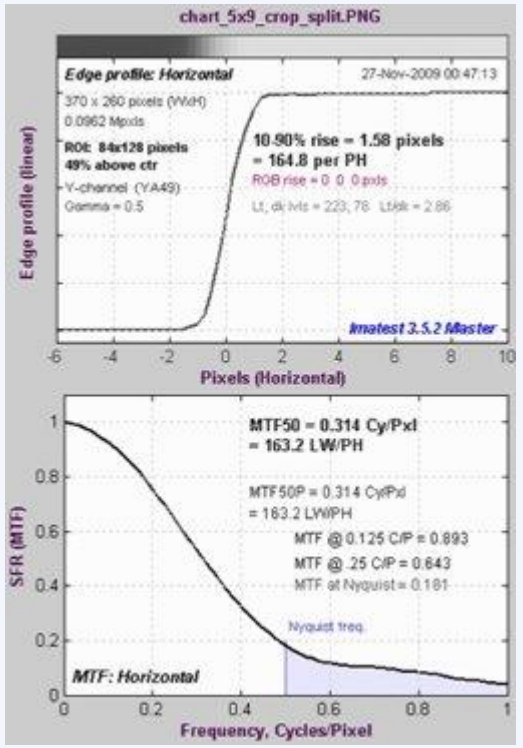
Color Accuracy

Light	Mean chroma (Sat) %	Chroma errors	
		(ΔC*ab)	(ΔE*ab)
A	103.2	10.2	7.45
U30	90.2	9.61	7.31
TL84	95.2	8.59	5.37
CWF	94.1	8.47	5.43
D65	98.0	7.74	4.21



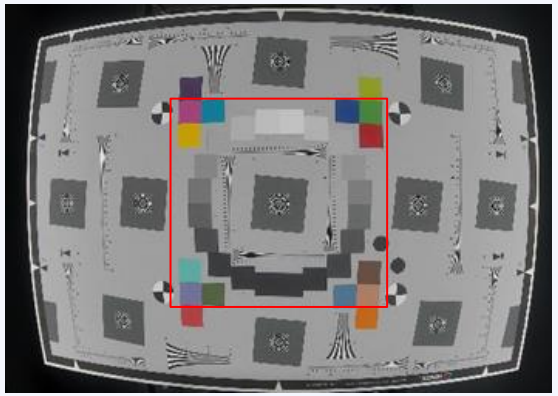
Spatial Frequency Response

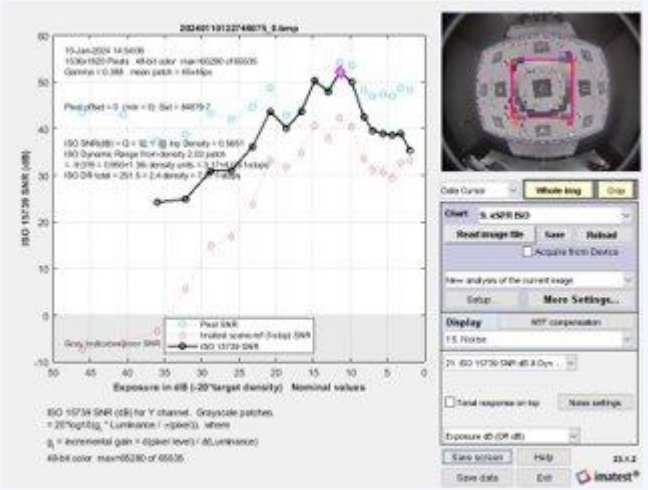
MTF50 (Cy/Pxl)	0.385



SNR

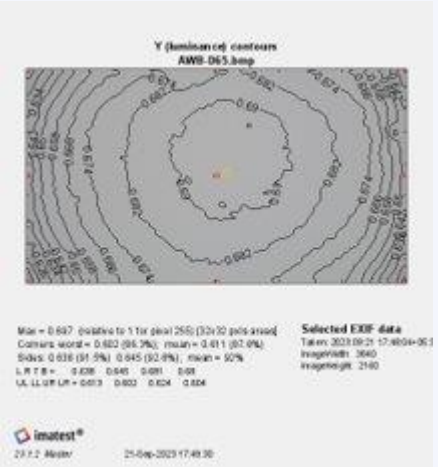
ISO SNR (dB)	38.7dB





Uniformity

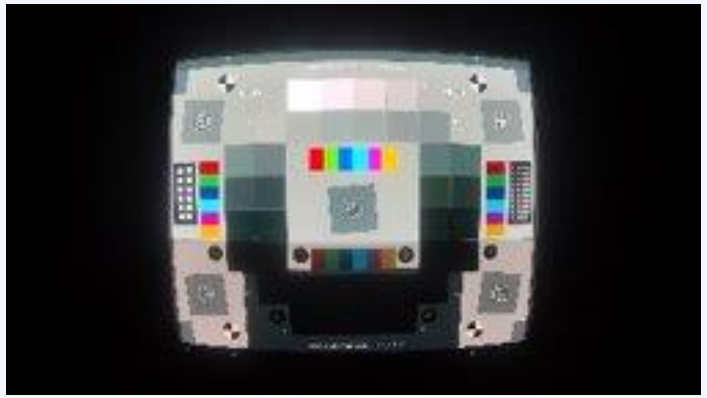
Corner% // Sides%
87.6 // 90



Dynamic Range

Indoor scene	Outdoor scene
	

Dynamic Range



113dB

How to fine-tune ISPs for different application demands

- **Based on Image Sensor and Lens**
- **Based on the Use Case**

- **Based on Image Sensor and Lens**
- **Based on the Use Case**

- Each sensor has to be matched with the De-mosaic algorithm depending on its CFA
- Tuned for color correction and white balance at different illuminant types (different CCTs)
- Lens shading correction and distortion correction are calibrated based on the type of lens and illuminant

- Based on Image Sensor and Lens
- **Based on the Use Case**

- Better color accuracy in low-light situations - increasing chroma noise in low-light
- Superior spatial frequency response at very high-frequency details – useful for recognizing text and small details (but causes aliasing artifacts)
- High SNR in low-light situations – performing denoising, which may impact scene details or sharpness

- Based on Image Sensor and Lens
- **Based on the Use Case**

High dynamic range can:

- Affect the overall contrast of the image, compromising small contrast variations in scene details
- Introduce transition noise and artifacts where the scene transitions from bright to dark

Certain algorithms or blocks take time to process each frame - leading to resolution and/or frame rate trade-offs

Case Studies:

How e-con Systems empowered clients with real-world ISP tuning

Surveillance systems

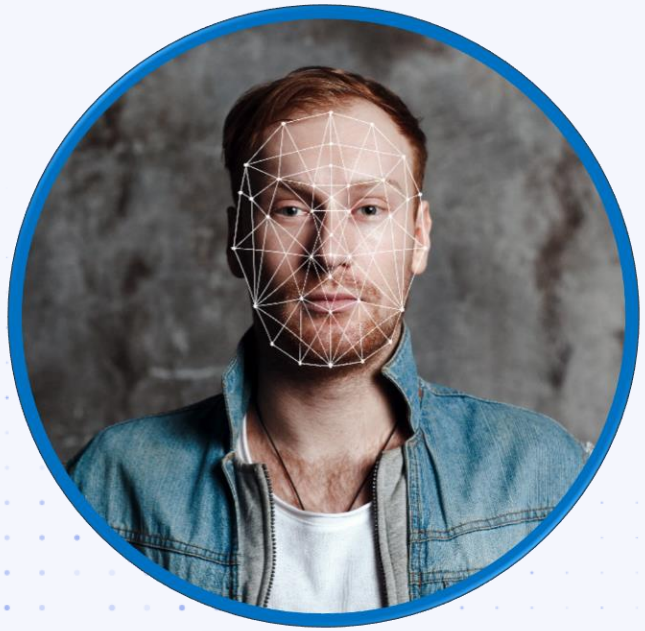
- Tuned for HDR, effective SFR without aliasing and 'pleasing to eye' color reproduction
- Requires typical full HD resolution and 30 fps
- Good SNR in low light and need for special CFA such as RGB-IR for superior day-night performance

Automotive cameras

- Need for capturing images at a higher frame rate - with HDR
- Need for good contrast over the entire scene's dynamic range
- End consumption - display or AI algorithms for object detection (pedestrian, lane, vehicle, etc.)
- Distortion correction algorithms for de-barreling the scene

Medical/Scientific Cameras

- Need for ensuring true colors without too much post-processing
- ISP must have full control over the color processing and output of the frames in uncompressed formats
- Demand for multispectral capabilities



Facial recognition-based access systems

- Auto exposure to be precisely tuned to illuminate the face properly
- Contrast and sharpness blocks to consistently bring out the details in the face at various lighting conditions
- Different skin tones to be truly reproduced with color tuning, as well as tuned auto algorithms and IQ blocks

Smart Agriculture Cameras

- Need for bringing out minor variations in the green color of the plants
- Tuned color accuracy to reproduce greens and sharpness without affecting the SNR

Emerging trends in ISP technology

AI and ML

Integration of AI and machine learning algorithms for advanced image processing and analytics

New-age ISPs

Development of ISPs for high-speed, real-time processing applications like autonomous vehicles and security systems

Energy saving

Focus on energy optimization for portable and battery-powered devices

Low-light performance

Improvements in low-light performance and high dynamic range capabilities

More use cases

Expansion into new applications such as medical imaging and industrial inspection

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Q & A

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