Bit Depth for Machine Vision Cameras

16, 14, 12, 10 & 8-bits cameras,
What does it really mean?

Bit depth = 10

1024 steps

256 steps
Analog vs. Digital

Sensor vs. Camera
Analog vs. Digital

continuous
(analog)

sampled
(digital)
Analog vs. Digital

+0.0450
+0.0223
+0.0135

1 2 3 ...........

+0.0135
+0.0223
+0.0450
+0.0789
+0.0929
+0.0934
+0.0766
+0.0478
+0.0205
+0.0111
-0.0132
-0.0277
Analog vs. Digital

Sensor vs. Camera

Analog Camera

Digital Camera

Analog sensor

Continuous

Sampled

- Analog vs. Digital
- Sensor vs. Camera
Definitions

SNR, Dynamic Range & Bit Depth
Definitions

Signal-to-Noise Ratio (SNR)

SNR is the ratio of the overall rms signal level to the rms noise level, expressed in dB.

SNR is the relationship between the usable intended signal and extraneously noise present, usually measured at the source. It is expressed in dB.

SNR is the amplitude of the signal compared to the noise. The higher the SNR the lower the number of errors.
Definitions

Signal-to-Noise Ratio (SNR)

\[
\text{SNR (dB)} = 20 \log\left( \frac{\text{Image e-}}{\text{Noise e-}} \right)
\]
### Definitions

**Signal-to-Noise Ratio (SNR)**

\[
SNR (dB) = 20 \log \left( \frac{\text{Image e-}}{\text{Noise e-}} \right)
\]

\[
= 20 \log \left( \frac{50,000}{200} \right) = 20 \log (250) = 47.96 \text{ dB}
\]

<table>
<thead>
<tr>
<th>Ratio</th>
<th>SNR (dB)</th>
<th>Bits</th>
<th>Pixel e-/200 e-</th>
<th>Pixel e-/50 e-</th>
</tr>
</thead>
<tbody>
<tr>
<td>256</td>
<td>48</td>
<td>8</td>
<td>50,000</td>
<td>13,000</td>
</tr>
<tr>
<td>512</td>
<td>54</td>
<td>9</td>
<td>100,000</td>
<td>25,000</td>
</tr>
<tr>
<td>1024</td>
<td>60</td>
<td>10</td>
<td>200,000</td>
<td>50,000</td>
</tr>
<tr>
<td>2048</td>
<td>66</td>
<td>11</td>
<td>400,000</td>
<td>100,000</td>
</tr>
<tr>
<td>4096</td>
<td>72</td>
<td>12</td>
<td>800,000</td>
<td>200,000</td>
</tr>
<tr>
<td>16384</td>
<td>84</td>
<td>14</td>
<td>3,000,000</td>
<td>800,000</td>
</tr>
<tr>
<td>65536</td>
<td>96</td>
<td>16</td>
<td>13,000,000</td>
<td>3,000,000</td>
</tr>
</tbody>
</table>
Definitions

System Signal-to-Noise Ratio (SNR)

Photon Shot Noise
Dark Current Shot Noise
Fixed Pattern Noise
Photo Response Nonuniformity
Reset Noise
White Noise I/F Noise
White Noise I/F Noise
Quantization Noise
Other Noise (system)

Array

Sensor (analog)

Sensor (digital)

Camera

Camera

sales@visionsystech.com
Definitions

Other Noise (system)

- spatial under sampling (beyond the limiting resolution)
- color reconstruction
- compression noise, if compression is used
- power line noise
- conducted noise from other equipment
- display noise (i.e. truncation, aliasing, wrong gamma)
- lens related distortion
- wrong image format (truncated bit depth)
Definitions
Dynamic Range

Dynamic range is the number of colors or shades of gray that can be represented by a pixel.

Dynamic range is a measurement of the number of bits used to represent each pixel in a digital image. The smallest unit of data stored in a computer is called a bit.

Dynamic range is the ratio of contrast, tonal range or density in an image between black and white. The number 0.0 represent white and black is 4.0.

Dynamic range is the measurement of the accuracy of an image in color or gray level. More bits of dynamic range results in much finer gradations being preserved.

Dynamic range is a term used frequently in numerous fields to describe the ratio between the smallest and largest possible values of a changeable quantity.
Definitions

Dynamic Range

Dynamic Range (DR) is the ratio of the maximum output signal, or saturation level, of an image sensor to the dark noise level of the imager.

The dark noise level, or noise floor of an imager is expressed as the root mean square (rms) variation in dark signal voltage.

\[
DR \ [\text{dB}] = 20 \log \left( \frac{V_{\text{sat}}}{V_{\text{Dark, rms}}} \right)
\]

\[
\text{SNR} \ (\text{dB}) = 20 \log \left( \frac{\text{Image e-}}{\text{Noise e-}} \right)
\]
Definitions

Dynamic Range

**DR [dB] = 20\log (V_{\text{sat}} / V_{\text{Dark, rms}})**

**SNR (dB) = 20\log (\text{Image e-} / \text{Noise e-})**
Definitions

Dynamic Range


sales@visionsystech.com
Definitions

Bit Depth

Bit depth is the number of bits used to define each image pixel, 24-bit color, 8-bit color, 8-bit grayscale, 1-bit bitonal. The greater the bit depth, the greater the number of tones (grayscale or color) that can be represented.

Also called pixel depth or color depth. Bit depth measures how much color information is available to display or print each pixel in an image. Greater bit depth (more bits of information per pixel) means more available colors and more accurate color representation in the digital image.

The number of bits per pixel determine the number of shades of gray or variations of colors that can be displayed.
Viewing the Image Bit Depth on a PC

What can be actually be seen?

4096 steps = 12 bits

256 steps
Viewing the Image Bit Depth on a PC

What can be actually be seen?

Bit depth = 10

1024 steps

256 steps
Display FAQs

- LCDs have a better contrast than Plasma.
- RGB settings are typically 0.55 or the inverse of 1.8.
- Contrast ratios are very important for good looking color images on LCD displays. As an example, a LCD monitor with 200:1 contrast cannot display an 8-bit image. Use LCD monitors with 400 to 512:1 or greater contrast ratio.
- LCD displays should have a brightness setting of at least 400 NITS for outdoor use (800 NITS is better). LCD's are brighter than Plasma displays.
- Video (analog) displays have a different gamma setting than RGB computer monitors (typically 0.45 or the inverse is 2.2).
Making the Bits

Quantization Errors from ADC’s
Making the Bits
Quantization Errors from ADC’s

\[ \frac{1}{\sqrt{12}} \text{LSB} \approx 0.289 \text{ LSB} \]

<table>
<thead>
<tr>
<th>A/D Converter Resolution (Binary Code)</th>
<th>(*Value of 1LSB)</th>
<th>0 to +10V Range (mV)</th>
<th>+10V Range (mV)</th>
<th>0 to +10V Range (mV)</th>
<th>+10V Range (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Bits (n)</td>
<td>Number Of Increments (2^n)</td>
<td>(mV)</td>
<td>(mV)</td>
<td>(mV)</td>
<td>(mV)</td>
</tr>
<tr>
<td>16</td>
<td>65536</td>
<td>0.152</td>
<td>0.305</td>
<td>0.076</td>
<td>0.152</td>
</tr>
<tr>
<td>12</td>
<td>4096</td>
<td>2.44</td>
<td>4.88</td>
<td>1.22</td>
<td>2.44</td>
</tr>
<tr>
<td>11</td>
<td>2048</td>
<td>4.88</td>
<td>9.77</td>
<td>2.44</td>
<td>4.88</td>
</tr>
<tr>
<td>10</td>
<td>1024</td>
<td>9.77</td>
<td>19.5</td>
<td>4.88</td>
<td>9.77</td>
</tr>
<tr>
<td>9</td>
<td>512</td>
<td>19.5</td>
<td>39.1</td>
<td>9.77</td>
<td>19.5</td>
</tr>
<tr>
<td>8</td>
<td>256</td>
<td>39.1</td>
<td>78.2</td>
<td>19.5</td>
<td>39.1</td>
</tr>
</tbody>
</table>

(*Note: scale 0 to 10 volt range to 0 to 1 volt for video)

And the percentage of quantization error for various ADCs can be seen in the following table.

<table>
<thead>
<tr>
<th>ADC Res</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q error (%)</td>
<td>0.113</td>
<td>0.056</td>
<td>0.028</td>
<td>0.007</td>
<td>0.0017</td>
<td>0.0015</td>
</tr>
</tbody>
</table>
Knowledge

Be more informed about technical specs
Some camera manufacturers say their cameras produce 14 bits, however, when you look at their own application notes, the performance is shown to have a dynamic range of 1320:1. That is amazing since a 11-bit dynamic range should be 2048:1 and a 10-bit dynamic range would be 1024:1. Therefore, claiming a 14-bit camera with a dynamic range of 1320:1, you can get the same performance out of a camera with an 11-bit dynamic range.
Conclusion

Be more informed about technical specs

- When in doubt, error on the conservative side
- Don’t promise more bits then we can produce
- Know some key numbers for SNR, Dynamic Range and Bit Depth