THE MOST IMPORTANT CAMERA PARAMETERS FOR AERIAL IMAGING

A look at the best choices for building an aerial imaging system

TELEDYNE LUMENERA **WHITE PAPER**

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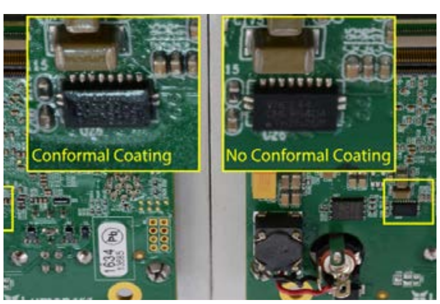

WHAT'S INSIDE

INTRODUCTION

Selecting components for an aerial imaging payload does not have to be complicated. This whitepaper walks through the specifications that matter the most when imaging from the sky. It covers the camera's resolution and sensor size, explains how sensitivity and noise are measured, discusses the required shutter type for aerial imaging, elaborates on dynamic range and bit depth, and highlights camera reliability considerations.

RESOLUTION AND SENSOR SIZE

Resolution is a commonly understood term thanks to consumer electronics such as DSLRs, point-and-shoot cameras, and smartphones. However, when it comes to aerial imaging, more megapixels does not necessarily translate to more ground resolution. Since ground sampling distance (GSD) is determined by the aircraft's height above the ground, the focal length of the lens used, as well as the pixel size, a higher camera resolution doesn't guarantee higher ground resolution.

For example, the Teledyne Lumenera Lt Series Cameras with Sony Pregius and Starvis global shutter and rolling shutter CMOS sensors. Available in 1.7 to 20 megapixel variants. It would be easy to assume that the LT-C/M4020 (12 megapixel) will yield a much higher ground resolution than the Lt-C/M2020 (3.2 megapixel). However, because both of these cameras use sensors with the same pixel size (3.45 microns), the ground resolution generated by each is the same for a given height above the ground and lens focal length. This can be seen mathematically using the ground sampling distance formula below:

$$GSD = \frac{(H \cdot px)}{f}$$

GSD: Ground Sampling Distance
H: Aircraft's height above the ground
px: Linear dimension of the pixel
Lens' focal length
**all units should be calculated in meters*

The formula makes no mention of "megapixels," only the size of each pixel. What ties more megapixels to more ground resolution is the sensor size. In other words, two cameras with identical sensor sizes and a different quantity of megapixels will have differing ground resolution, where more megapixels now equates to more ground resolution.

What changes in our example is the camera's field of view or the amount of total visual information that is captured by the camera. When used with a lens that is matched to the camera's sensor size, the LT-C/M4020 captures roughly double the image height and double the image width of the Lt-C/M2020. This is because the LT-C/M4020 is equipped with a 1.1-inch sensor, whereas the Lt-C/M2020 uses a 1/1.8-inch sensor.

Larger sensors provide a wider imaging swath and, therefore, require fewer passes over an area to conduct an aerial survey. This translates to less time in the air, less fuel consumed, and lower overall operating costs.

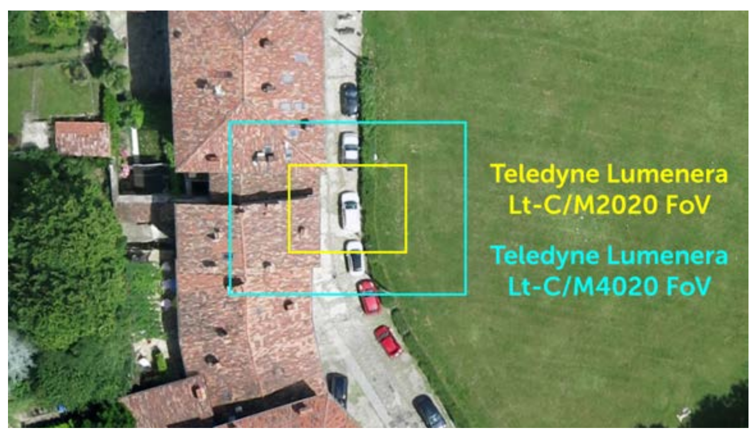

Figure 1 – Field of View Comparison Between Teledyne Lumenera Lt-C/M2020 and Lt-C/M4020 Cameras

However, using a large camera sensor is not the only solution to increasing pixel width in aerial imaging. By using multiple cameras instead, two smaller sensors placed side-by-side and synchronized can result in even greater pixel width. To learn more read our whitepaper, Using A Single Versus Multiple Cameras In Aerial Imaging.

The bottom line: pixel size is what dictates ground resolution in an imaging payload, not the number of megapixels and sensor size is what will determine the field of view once a lens is selected to properly match the camera. For more information on sensor size, read the Teledyne Lumenera blog post.

SENSITIVITY AND NOISE

It is understandable that the camera selected for an aerial imaging application should have as little read noise as possible and very high sensitivity. However, it is helpful to understand where these parameters come into play with the imaging payload.

DEFINING SENSITIVITY

A camera's sensitivity can be defined using a number of different units. EMVA 1288 defines a camera's absolute sensitivity threshold as the number of photons required to increase a pixel's value by one. This, however, does not take into account the pixel's size. If two pixels require the same number of photons to reach their absolute sensitivity threshold, and one is twice as big as the other, the larger one actually requires less light and is more sensitive than the smaller one. This is why Lumenera illustrates sensitivity in units of:

$$\frac{DN}{nJ/_{cm^2}}$$

DN: Digital Number
nJ: nanojoules
cm²: square centimeters

If DN is set to one, this will illustrate the amount of light energy required to fall on the area of a pixel to increase the pixel's digital number by one. This allows for a more direct comparison of sensitivity because it normalizes for the size of the pixel. A full mathematical explanation can be found in our blog post: Understanding Camera Sensitivity – A Look at the Numbers.

The bottom line is that the higher the sensitivity value specified in the camera's datasheet, the less light is required to obtain a usable signal that is above the noise floor.

DEFINING NOISE

The noise floor is dictated by the sum of all sources of noise in the imaging system. The two main sources of noise that are determined by the camera are read noise and dark current noise. Read noise occurs each time the camera takes an image and dark current noise is both thermal and time dependant. The longer the exposure and the hotter the camera, the more dark current noise is generated. These noise sources are listed on the datasheet in units of electrons and electrons per second, respectively. This specifies the number of electrons that can be unintentionally freed from the sensor's semiconductor lattice structure and then readout as signal.

HOW SENSITIVITY AND NOISE IMPACT FLIGHT

The camera's sensitivity directly impacts the length of the exposure time that can be used. More sensitivity allows for faster shutter speeds. As explained in our blog post, The Challenge of Aerial Imaging: Achieving a Clear and Sharp Image, an aircraft's speed is limited by motion blur which is directly tied to the camera's shutter speed. Therefore, a camera with higher sensitivity allows the aircraft to travel at higher speeds because it is able to use shorter exposure times.

Noise is tied to the camera's gain (multiplier circuit that is part of the camera's sensor). Since gain amplifies both signal and noise indiscriminately, lower noise allows for higher gain to be used while maintaining image data integrity. This allows for even shorter exposure times to further increase the aircraft's groundspeed.

To learn more, read our blog post, Configuring a Camera: How Exposure Time and Gain Impact Image Noise, to see examples of camera gain and exposure time at work and their impact on image noise.

SHUTTER TYPES

Cameras typically come with one of two types of shutters – global or rolling. A rolling shutter consists of exposing each line of the sensor one at a time and in rapid succession, whereas global shutters expose all pixels at once. Rolling shutters are subject to blurring or smearing of an object if it is moving at a high rate of speed through the frame during exposure. Global shutters eliminate these artifacts because they freeze moving objects in place by exposing every pixel at the same time. Traditionally, CCD sensors were the only ones to function with global shutters, leaving rolling shutter functionality to CMOS sensors. However, as CMOS technology has dominated CCDs, there are now several types of high quality global shutter CMOS sensors available, such as Sony's Pregius sensors as well as roling shutter sensors like Sony Starvis sensors.

Figure 2 – Image with Skew Caused by a Sensor With a Rolling Shutter

THE IDEAL SHUTTER TYPE FOR AERIAL IMAGING

Global shutter cameras are the only viable option for aerial imaging if maximizing groundspeed is important. Similarly to the blur calculations, if a rolling shutter camera is used, the movement of the aircraft introduces artifacts into the image because each row of pixels is exposed with a slight delay to the neighboring row. This introduces skew into the image as seen Figure 2.

DYNAMIC RANGE

Dynamic range is a quantifiable method of determining how well a camera can see into shadows. In other words, it expresses the range of brightness levels that the camera can extract detail from in a single image. With industrial cameras, dynamic range is typically specified in decibels, which is a logarithmic scale.

Figure 3 – Comparison of Low Dynamic Range and High Dynamic Range

The equivalent to this to this in the consumer photography world is "exposure value" (EV) or "stops." Stop is derived from "f-stop" which is used to measure a lens' aperture. Each time the aperture is increased by a full f-stop, the amount of light that is let through to the lens doubles.

Here, dynamic range is evaluated in terms of how many stops the camera can cover in a single exposure. To convert dynamic range in decibels to dynamic range in stops, use the following formula where DR is dynamic range:

$$\frac{DR_{dB}}{6} \approx DR_{Stops}$$

Note that that dynamic range is not the same thing as the signal to noise ratio. While both can be expressed in decibels, dynamic range is the entire range that the camera can cover, whereas signal to noise ratio is dependent on the available signal and will always be less than the dynamic range.

A wider dynamic range allows for a wider range of possible signal to noise ratios to be present in an image. A complete explanation of the difference between SNR and dynamic range can be found in our blog post: Understanding Dynamic Range and Signal to Noise Ratio When Comparing Cameras.

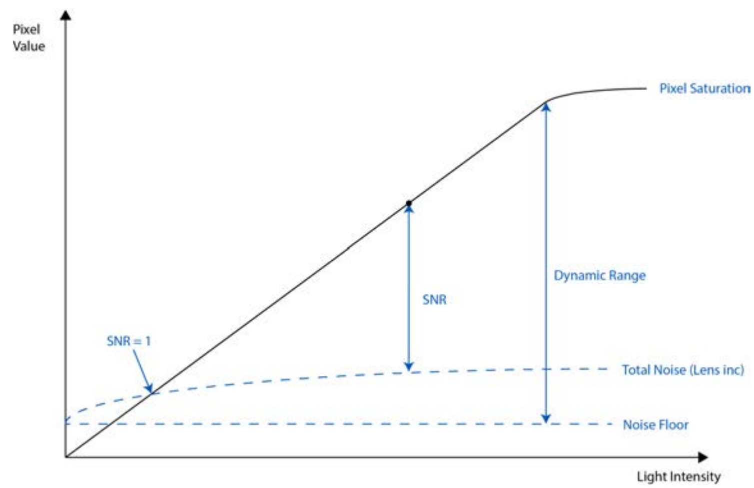

Figure 4 – Illustration of SNR and DR with Respect to Pixel Value vs Light Intensity

BIT DEPTH

The bit depth of a camera indicates the precision with which each pixel is measured. Bit depth comes from the binary nature of data that is stored electronically. Each bit can have a value of either zero or one. Each additional bit unlocks double the data, as it is an exponential relationship. The number of available shades per pixel can be calculated by taking two to the power of the bit depth.

HOW MANY BITS DO I NEED?

Bit depth requirements are dictated by the system's design. If the visual data generated by the camera is meant to only be viewed by humans then the standard 8-bits of depth per color channel is sufficient. However, if analysis or measurements, such as NDVI or aerial photogrammetry are to be performed on the data, then higher bit depths will be required.

ADDITIONAL CONSIDERATIONS IN RELIABILITY

Camera reliability is a factor that should be considered when selecting a camera for an imaging payload. However, it is not something that can be easily determined or compared from a datasheet. Factors like maximum and minimum operating temperatures can be compared, but they do not tell the whole story.

Industrial grade cameras are a great starting point for reliability. Unlike consumer-grade DSLRs, they are designed specifically for continuous use in less than ideal operating conditions. With rugged designs that allows for continuous use in harsh environments.

ELECTRONIC SHUTTER

Industrial grade cameras also typically have electronic shutters instead of mechanical which can be beneficial to aerial imaging in two separate ways. First, electronic shutters are vibration-free because there are no moving parts. This helps to further reduce blur to achieve clear and sharp images. Second, no moving parts mean that the camera is not susceptible to mechanical failures over time which is common with cameras such as DSLRs.

CONFORMAL COATING

Lumenera has the ability to further the camera's durability by performing customizations such as using a conformal coating to provide additional protection to the camera's circuit boards. Conformal coating helps to reduce the risk that condensation poses to the camera's internal circuitry by applying a very thin polymer membrane to the PCB. You can read all about conformal coating in our blog post: Protecting Aerial Imaging Equipment with Conformal Coating.

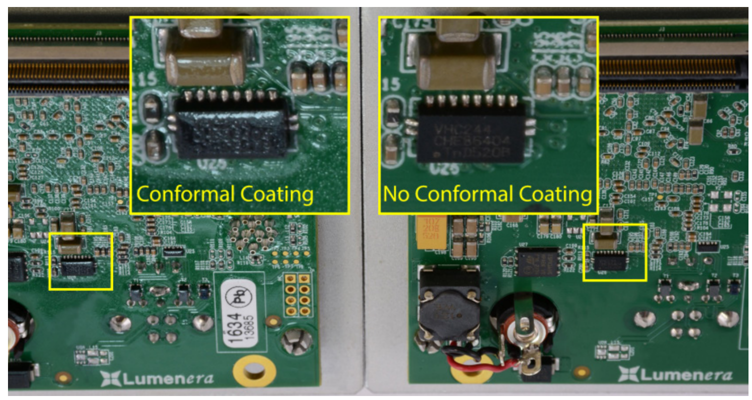

Figure 5 – Comparing two identical circuit boards - one with conformal coating, one without

SIZE WEIGHT AND POWER (SWAP)

Small size, low weight, and reduced power consumption is key for unmanned aerial systems. This allows for longer flight times and a more compact design. Teledyne Lumenera Lt Series industrial cameras are a great option to consider for UAS payloads because their USB3 interface that require much less power than their many alternatives. Equipped with side mounted connectors that allows them to have a thinner form factor. Teledyne Lumenera also manufactures equivalent Lt Series Board Level Cameras for even further reduced payloads.

CONCLUSION

Ground resolution is dictated by pixel size, not megapixels. While smaller pixels provide greater ground resolution, an aircraft's speed is also dependant on the combination of pixel size, height above the ground, and the lens' focal length – where smaller pixels will limit the speed of the aircraft.

Sensitivity and noise are two parameters that also influence an aircraft's maximum speed. The more sensitive the camera, the less exposure time is required and the faster the aircraft can fly. With noise, a lower read noise means more gain can be used while maintaining a usable image – allowing a shorter exposure time for an increase in groundspeed. A global shutter is also essential when imaging from a moving aircraft to avoid image skew associated with global shutter cameras.

A heightened dynamic range is extremely helpful for imaging shaded areas on the ground while maintaining visibility in well-lit areas. Typically measured in decibels for industrial cameras, dynamic range is easily converted into "stops" by dividing by six. Required bit depth is determined by the application. If the images are being viewed with human eyes, 8-bits of data per color channel are sufficient. However, for applications where measurements are being made, such as NDVI and photogrammetry, higher bit depths are required.

Camera reliability is essential when capturing mission critical images, but is difficult to quantify in terms of specifications. An industrial camera is a good starting point. Some customization options, such as conformal coating, can also help protect against condensation forming on the electronics at high altitudes.

If you have questions about camera specifications for your aerial imaging payload, reach out to our imaging experts at lumenera.info@teledyne.com.