Talking Digital

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Introduction

Growing customer demands in Geographic Information Systems (GIS) are driving the capture through delivery demands of remote sensing. Advances in global positioning, digital aerial data capture and storage technologies play a critical role in supporting GIS functionality. The technology to add and distribute digitally captured image files to and from your GIS is as easy as picking up the telephone. The market has created new issues around image quality; one issue of keen interest is scale versus resolved data in a digital file.

Image Scale & Ground Sample Distance

A common frame of reference is lost as users move to softcopy. The dialog encountered between analog and digital user often sounds the same; there is a natural tendency to use terminology based on traditional methods; scale, line pairs per mm, and Ground Resolved Distance (GRD). However, without a clear understanding of the digital domain, what was once known as a discernable object from 1:2400 scale images may appear as a fuzzy digital blob once you can zoom and scale data at the touch of a button.

Scale has been a fundamental measure of utility and quality for many decades with hardcopy imagery. However, a digital image file does not have a scale *per se*; it can be displayed and printed at many different scales. Furthermore, modern softcopy display software allows for rapid change in viewing scale. Of course, scale has not become irrelevant. However scale is a function of the device and processing used to display or print the file, not an immutable property of the image file itself. Of some concern, therefore, is the fact that users have been long attuned to assigning a level of photo interpretability based on scale. With digital imagery, ground sample distance (GSD) provides a more appropriate metric.

Ground sample distance itself must be qualified to avoid ambiguity. Digital imagery may easily be resampled to alter the ground sample distance, either on the fly for screen display or as a step toward creating a new, permanent image file derived from the original. Collection, product, and display GSDs can be very different for the imagery from the same source. We first consider the *collection GSD* of a digital imaging system.

The lens of an airborne digital camera forms an image of the ground on its focal plane at a certain scale. That *camera scale* is the ratio of focal length of the lens and to the collection height above ground level (AGL),

camera scale = (focal length)/(height AGL).

For example, a camera with a 28 mm lens flying at an altitude of about 1800 m AGL will form images with a scale of roughly 1:65,000 on its focal plane. If the image in the focal plane is then sensed by a charge-coupled device (CCD) array, then the collection GSD is the ratio of the array element size, to the camera scale,

collection GSD = (array element size)
(height AGL)/(focal length).

In general, GSD is simply the linear dimension of a single pixel's footprint on the ground. (However, due to other factors, it is not necessarily what one will be able to resolve in an image.) To continue the previous example, if the array element size is about 0.009 mm, then the collection GSD is about 0.6 m (2 feet).

Digital imagery is rarely, if ever, printed or displayed at the camera scale itself—that's usually much too small for display digital printers and displays. Again continuing our example, suppose the CCD array is 3000 pixels wide. Then if one prints an image on a 300 pixels-per-inch (ppi) dye-sublimation printer, it will be about 10 inches wide. The scale of the image may be computed directly from the collection GSD and the printers' "pixel size." The nominal pixel size is about 0.085 mm for a 300 ppi printer. Dividing by the collection GSD we have about 1:7000. That is,

display scale = (display pixel size)/
(collection GSD).

Considering display on a screen with a typical "dot pitch" of about 0.3 mm, the display scale for 1:1 display of image pixels to screen pixels would be about 1:2000.

Figure 1 is a print of an image collected with a system having the parameters described in the preceding example, and georegistered with a nearly 1:1 resampling ratio. The result is an image that overlays a map with pixels precisely 0.6 meters in dimension. This brings us to the notion of *product GSD*. The product GSD is the real-world size of a pixel in a digital image product after all rectification and resampling procedures have occurred. In the case of Figure 1, the product GSD matches the collection GSD. At this particular product GSD of 0.6 m, one cannot have a substantially sharper image.

Readers can check the display scale of the printed examples for themselves by measuring the length of the tennis court in Figure 1. It is 40 pixels tall, from baseline to baseline, in the digital image. Multiplying by the product GSD of 0.6 m, we find a length of 24 m for the court (which matches the regulation size of 78 feet to the sub-pixel level).

However, a given product GSD does not guarantee certain level of

FIGURE 1. 800 pixel x 800 pixel portion of a digital orthoimage with 0.6-m (2 foot) collection and product GSD. The image was acquired with a 28 mm lens and a CCD array pixel size of 0.009 mm at an altitude of about 1800 m AGL over Cincinnati, Ohio.

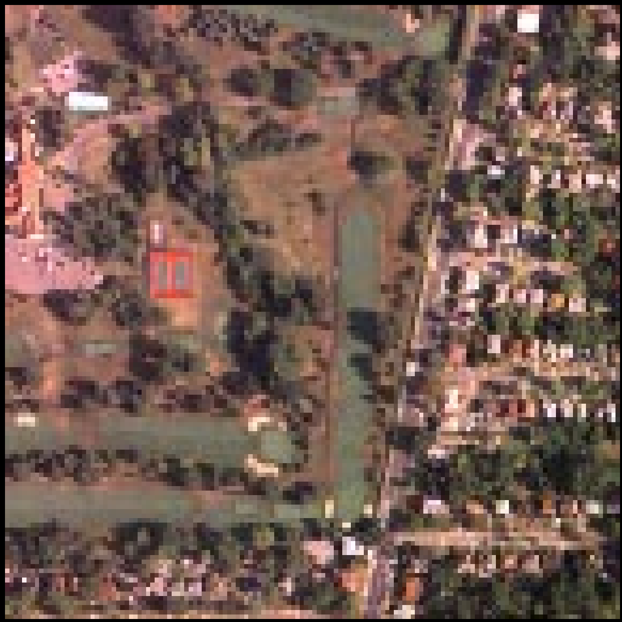

FIGURE 2. 800 pixel x 800 pixel portion of a digital orthoimage with simulated 1-m collection and 0.6-m product GSD. The display scale and extent are the same as in Figure 1.

FIGURE 3. 800 pixel x 800 pixel portion of a digital orthoimage with simulated 3-m collection and 0.6-m product GSD. The display scale and extent are the same as in Figure 1.

FIGURE 4. 800 pixel x 800 pixel portion of a digital orthoimage with simulated 10-m collection and 0.6- m product GSD. The display scale and extent are the same as in Figure 1.

resolution, it only specifies a maximum. Figures 2, 3, and 4 were formed by simulating imagery at collection GSDs of 1, 3, and 10 meters, respectively. Each simulated image was then orthorectified and resampled to a product GSD of 0.6 m. Furthermore, each is printed at the same scale. It should be clear that scale does not tell the whole story for digital imagery! And neither does product GSD—unless the collection GSD of the imagery used to make the product *equals or exceeds* the product GSD itself.

GSD clearly affects product quality and utility. A 1:2400 scale image map with 1-foot versus 1-meter GSD will clearly evoke different feelings from a user. A smaller product GSD leads to a larger digital image, however. GSD along with levels of quantization, number of bands, and size of coverage must be traded against ease of data handling.

As we formerly specified scale we must now be cognizant of sampling criteria of the target. To say 1:2400 output scale is clearly insufficient, we must understand the target versus its background. One should evaluate the number of pixels required to resolve a target. Rarely in life will the user be so fortunate that a 1 meter pixel will lie directly on a manhole cover. Consideration of target resolution must also incorporate its background differentiation. GSD is probably the most descriptive and it is commonly used by both aerial and space system users. As such, a strong understanding of its relationship with other system parameters is critical.

Factors Affecting Image Quality

• **Array sensitivity** — Most digital cameras being used in today's market use charge coupled devices (CCDs). CCDs are sensitive to wavelengths from 0.4 µm up to about 1.1 µm in the spectrum. In practice, however, CCDs yield less than 10% response above 0.9 µm. By using the appropriate CCD and spectral filters the array provides nearly identical true color or false color IR that is comparable to traditional films. The CCDs offer much broader dynamic range, this is evident especially with 12-bit collection from low altitude. Here, data is retained in both highlight and shadow detail.

• **Lens Falloff** — As in any lens system, a cosine power law applies so a correction should be applied to compensate for lens falloff.

• **Band Registration** — Lack of band registration can be a direct source for degrading resolution. Perfect band registration is achievable and it enhances the image quality.

• **System Modulation Transfer Function (MTF)** — During construction of each component of the camera, the manufacturer gets a measure of its output quality via the MTF. Cascading (multiplying) the MTFs from lens, detectors, and so on, gives a measure of the image quality from the total system. This is true in either film or digital systems. A good MTF generally means sharp edges and high system resolution.

• **Atmosphere/Environmental Conditions** — Unfortunately, flying conditions resulting from the weather can change the quality of the image severely. For example, a hazy day, or smoke, or improper sun angle takes its toll on image quality. The increased dynamic range of the digital sensor allows the digital camera to achieve images in lower light levels than is possible with film systems.

• **Scene Contrast and Shadows** — In general, the Earth scene as a whole is a low contrast target; say 1.6 to 1. Tall buildings, trees, and mountains often cast shadows when imaging in low sun angles. Shadows, therefore, may appear very dark, inhibiting the human eye from interpreting the detail in the shadow. A well exposed film system yields about 180+ gray levels, whereas a digital system with a 12-bit quantization per pixel will record 4096 levels. Image manipulation software can be used to get the maximum detail from the shadow or low contrast scenes. The more levels recorded, the more likely the detail can be brought out in the shadow areas.

What Effects Interpretability?

• **GSD** — Although it is a very important measure of a system's capability, the term GSD is often misused. For example, a 1 m GSD does not mean that you can resolve a target on the ground 1 m in size. One pixel can only depict that something is there. For visual identification, 4 to 9 pixels within the object are needed to resolve the object of interest.

• **Radiometry** — For any imaging system to produce good results there must be contrast differences between the target and the background. For example, if a field and the road next to it are quantized the same by the camera, then the road will not be visible and interpretable. Interpretability is always a good measure of end utility for imagery, but those measures are often closely related to GSD, quantization (bits per pixel) as well as ground resolved distance (GRD). GRD is closer to an interpretability scale than GSD. Both have their proper place for usage. But, GSD is a physical attribute that will not vary whereas, GRD is effected by a variety of other factors. Using imagery for automated pattern recognition is heavily effected by GSD. Techniques that work well at one GSD may not necessarily work well at increased or decreased GSD.

• **Resampling** — Resampling is the technique that changes the GSD of a digital image. In one sense, resampling a digital image accomplishes about the same thing as enlarging or reducing a film image, even though the two processes are entirely different. In the digital domain, resampling is done to change the original image to a product for display, for printing or to geometrically transform the image to be georeferenced. In almost all cases, the product delivered to the customer has been resampled and changed from its original collection scale. The resampling process causes the need to talk about collection GSD (GSD at the original scale) and product GSD as well as display GSD. Product GSD and display GSD can be useful terms, but they also can be confusing. Perhaps it would be better understood to leave GSD to refer to the ground sampled distance from the original collection and for product GSD and display GSD to be thought of as product pixel size and display pixel size. In any case, the GSD in the digital domain remains a key metric and is the expression for quality in the digital camera domain.

• **Compression** — Compression can act as a form of resampling. The goal is that of file size reduction. Multiple forms of compression exist. DPCM, DCT, and Wavelets are common examples. Each utilizes math models of the scene to reduce the storage space required to characterize pixel values. As a rule of thumb, 3-to-1 or lower is considered near loss less. The largest concern is data loss. Loss can come in radiometric, spatial displacement, and frequency forms. The most graphic representation utilizes a pixel-by-pixel difference map of the original file versus its compressed format. Here the user can derive a visual representation of loss.

Summary

The time proven mapping camera (9 x 9 inch format) has been the workhorse in the aerial photogrammetric business for years, and it will continue to play its role for several more years. On the other hand, digital cameras are moving at the speed of technology to find their niche in the aerial imaging market. It is the intent of this article to promote dialogue among both film and digital camera users and builders so that terminology and standards will promote better understanding and communication in the future.

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