THE NEXUS OF GROUND SAMPLING DISTANCE OPTIMIZATION AND UAV-BASED ENGINEERING SURVEYS

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Keywords: resolution, accuracy, management, productivity, systematic approach, aerial planning, efficiency.

SUMMARY

Ground Sampling Distance (GSD) is a cornerstone in modern engineering surveys, setting the level of detail we can achieve in mapping and measuring the world around us. At its core, GSD tells us the "resolution" of an image, directly affecting the accuracy and detail captured, whether from drones, satellites, or ground-based sensors. This paper dives into how GSD impacts real-world engineering projects—like tracking volumes in mining or monitoring structures in construction—and explains how fine-tuning GSD settings can lead to more precise data for planning, monitoring, and decision-making.

We cover the basics of how GSD is calculated, including factors like the camera's resolution, the height of the flight, and the lens used. Practical examples show the balancing act surveyors face: for instance, a very detailed (small) GSD provides sharp and accurate data, but it comes with trade-offs like higher costs and larger data files. With technology advancing rapidly, the demand for sharper data at lower costs has led to innovations in AI, adaptive sensors, and automated data processing, all reshaping how we approach GSD.

This paper ultimately sheds light on why understanding and managing GSD is crucial for survey engineers who want to capture the most reliable and usable data without over - extending resources. As we navigate challenges like increased data demands and evolving tech, GSD remains central to achieving quality, efficiency, and precision in engineering surveys.

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GSD and Calculation

Ground Sampling Distance is the distance on the ground represented by a single pixel in an image. In simpler terms, the GSD represents the size of one pixel on the ground.

Ground Sampling Distance is mostly dependent on four (4) things which are:

- The flight height
- The Sensor Resolution (pixel size, megapixels and dimensions)
- The focal length of the camera
- Image height

Why You Should Know Manual GSD Calculations

Even though GSD calculators automate the process, understanding manual GSD calculations is crucial for several reasons:

1. Fundamental Understanding of Remote Sensing Concepts

- Knowing how GSD is derived helps you understand spatial resolution, scale, and image accuracy in remote sensing and GIS.
- It allows you to determine whether an image has the required level of detail for applications like flood risk assessment, urban expansion studies, or powerline monitoring.

2. Verification of Automated Calculators

- GSD calculators can sometimes produce incorrect results due to wrong inputs, software bugs, or unit conversion issues.
- If you know the manual calculations, you can cross-check and validate the accuracy of automated tools.

3. Customization for Specific Applications

- Some GIS or remote sensing projects might require custom GSD adjustments based on flight altitude, sensor specifications, or project requirements.

- Manual calculations help when standard GSD calculators do not offer flexibility for unique cases.

4. Troubleshooting and Error Detection

- If a GSD calculator provides unexpected results, you can manually compute GSD to identify and correct errors.
- This is especially useful in research projects or when working with new sensors where GSD values need careful validation.

5. Practical Use in Fieldwork and Data Collection Planning

- In drone and aerial surveys, knowing GSD calculations allows you to plan flight parameters (altitude, camera settings) to achieve the desired spatial resolution.
- This helps optimize data collection without relying solely on software.

6. Professional and Academic Advantage

- Understanding manual GSD calculations sets you apart as a competent GIS or remote sensing expert, rather than just relying on software outputs.
- Many academic and professional certification exams in geospatial sciences, photogrammetry, and remote sensing require knowledge of GSD formulas.

The GSD Formular is calculated by:

GSD = (flight height x sensor height) / (Focal Length x Image Height)

Alternatively, ***GSD*** = (flight height x sensor width) / (Focal Length x Image Height)

Below is a manual calculation for flight height of 80m.

$$GSD_h = \frac{Flight\,Height * Sensor\,Height}{Focal\,Length * Image\,Height}$$

$$GSD_w = \frac{Flight\,Height * Sensor\,Width}{Focal\,Length * Image\,Width}$$

- Image Width: 5472px
- Image Height: 3078px
- Sensor Width: 13.2mm
- Sensor Height: 8mm
- Focal Length: 8.8mm

So, substituting the values (in centimeters) into the formulas, we get this:

$$GSD_h = \frac{8000 * 0.8}{0.88 * 3078} = 2.19$$

$$GSD_w = \frac{8000 * 1.32}{0.88 * 5472} = 2.36$$

You'll use the greatest value (or the worst case scenario), so in this case: **GSD = 2.36cm/px.**

Effects of GSD on Engineering Surveys

GSD is the main drive of any UAV based mission. The purpose of the mission will induce the GSD that ought to be achieved. Below, we have an analysis of a Low GSD and a High GSD.

Low GSD

Lower GSD means a higher resolution. Any mission with lower GSD has more details with respect to pixels. This indicates that each pixel represents a smaller area on the ground which results in a sharper and more detailed delivery. In engineering surveying, there are various aspects that are usually advised to achieve lower GSD according to the error margin in place. Such are as follows: -

Stockpile Volumetrics

For stockpile volumes, a lower GSD will be closer to the true value as compared to a higher GSD. This is because the dense cloud points will have much details and would be more precise compared to the actual on the ground.

Deformation Analysis

For deformation analysis, very little movements are very key. In fact, higher GSD for deformation analysis will not even depict the level of deformation needed as compared to a lower GSD.

Topographical Surveys

This is one of the most important aspects with respect to engineering when it comes to projects. Topographical Surveys depict the terrain of an area. This is what we term as Digital

Terrain Model (DTM) which is a type of Digital Elevation Model (DEM). A lower GSD model for a topographic survey will contain more details of the topography as compared to a higher GSD model. Where there are swift significant changes on the elevation, the model would be able to pick these elevation changes because the pixel of the model represents a smaller area on the ground.

If there are rocks, humps, ramps or any other little changes in elevation, a lower GSD model will depict these little changes in elevation better. This is a very important aspect of engineering surveys.

Measurements and Detailing

When it comes to measurements and details, an image with a lower GSD would measure accurate details and measurements than an image with a higher GSD. Picking measurements of buildings of an image with higher GSD would be far from the true measurements on ground because the pixel size would cover a bigger area on the ground as compared to a lower GSD. Hence, digitization on low GSD images produces better and more accurate results.

Disadvantages of Low GSD

- Low GSD Models require bigger storage. This is because the lower the flight height, the more images the UAV captures. This affects the storage needed to execute a task, storage needed to process the mission and storage to storage to export the deliverables. This means you need to invest a lot in either cloud storage or hard disk storage for your missions
- Low GSD Models require high performance computers. Due to the size of low GSD Models, the RAM and ROM of your computer must be significantly huge to accommodate and process such models effectively. You will need a computer with a very good and high processing capacity to also execute such missions.
- Low GSD Models are more time consuming. The time it takes to even capture an area with low GSD will be more because the UAV will need to move a lot to cover the said area as compared to a high GSD mission.
- Low GSD Models require more batteries for data capture. In photogrammetry, drone batteries are very significant in mission execution. You will be forced to purchase more drone batteries to finish a mission in time.
- Overall, the Low GSD Models are very expensive.

High GSD

Having a model with a higher GSD can also be useful in its own special way even though the resolutions may be lower. This indicates that each pixel represents a larger area on the ground which results in a blurry and less detailed delivery. Aspects of engineering surveys that make very efficient use of High GSD models are as follows: -

Large Scale Topographic Mapping

Large scale topographic mapping is one of the areas that can still make use of a High GSD model. This can serve as a base for modeling and designing of earthworks. Large topographical analysis such as water flow analysis, site suitability and feasibility analysis, etc. can also rely on high GSD models. This is mostly useful for base modeling and designing for earthworks.

Planning

Planning in many forms can be done efficiently with higher GSD maps. This can serve as a base map for various forms of planning. Urban and rural planning can make good use of High GSD Models. Site planning for projects can also make good use of High GSD Models since they do not necessarily require high levels of detail and resolutions.

Management

Management of projects finds it easy to relate and take significant decisions with respect to their sites. They are able to modify and make changes to the general plans of the project and makes execution of such modifications very easier since it makes easier for subordinates to understand and appreciate Management's perspective and views. Management on the other hand also finds it easy to hold virtual discussions which save a lot of time and money.

Disadvantages of High GSD

Just like the Low GSD Models, the High GSD Models also has disadvantages.

- High GSD Models can limit you with respect to the data at hand. You will most likely have to confirm majority of the measures carried out by such models.
- Analysis that can be carried out on such models are very few.
- High GSD Models come out with low resolutions. Objects easily pixilate when you to zoom in.

Practical comparison between Low GSD and High GSD

FEATURE	LOW GSD	HIGH GSD
Pixel Size	Smaller	Larger
Image Detail	Higher	Lower
Data Accuracy	Higher	Lower
Flight Altitude	Lower	Higher
Image Capture	More Images	Fewer Images

Practical Analysis

As part of this paper, we performed some experiments and missions to confirm a few of the situations.

Below is a stockpile of ore material at the ROMPad of one of the mining companies in Ghana. These surveys are done to calculate the volume of ore that is mined from the pits. This aids the mine to plan an estimated ounces at the end of the shift. This volume also serves as a base for invoicing mining contractors on the mine.

This hence becomes a very sensitive area to handle because misinformation might cause a lot of damage. Amongst the several materials dumped, we focused on one stockpile for our case study. We had 2 case studies. We had a mission at 80m altitude and another at 200m altitude. Per the analysis above, we know how different the 2 with different GSDs will be.

With the aid of photogrammetry software, we run the volumes as well on both missions.

Below are the volume results of both missions: -

Label	Perimeter (m)	Area (m²)	Volume (m³)		
			Above	Below	Total
2	76.498	380.632	472.183	5.001	467.181
Total	**76.498**	**380.632**	**472.183**	**5.001**	**467.181**

Measurements

Base plane for volume calculation: best fit plane

200m altitude with GSD of 5.37cm/pix provided a volume of 467.181m3

Label	Perimeter (m)	Area (m²)	Volume (m³)		
			Above	Below	Total
2	76.498	380.632	466.202	3.451	462.751
Total	**76.498**	**380.632**	**466.202**	**3.451**	**462.751**

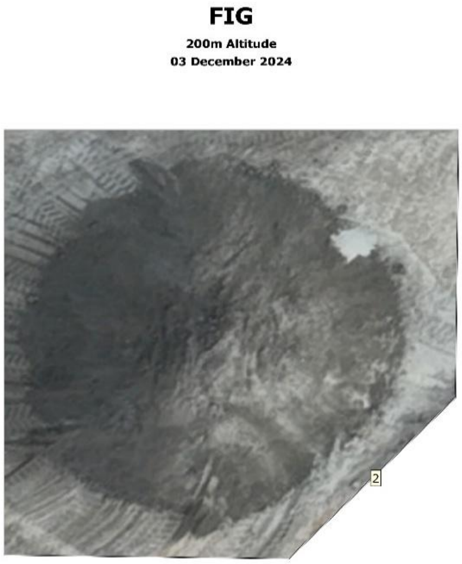
Measurements

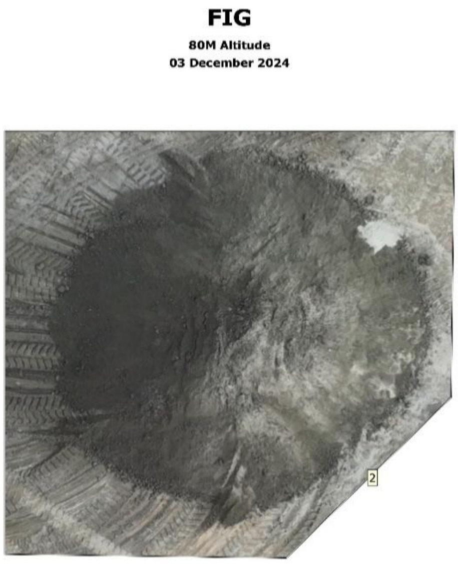
Base plane for volume calculation: best fit plane

80m altitude with GSD of 2.15cm/pix provided a volume of 462.751m3

Out of about 38 stockpiles, this particular stockpile was one of the smallest on the ROMPad. Considering the volume of material situated at the ROMPad, 5 *cubic metre* difference can be very significant on a large scale.

With respect to resolution, both images can be seen below: -





From the results above, it is very evident the clarity of the images. The lower altitude due to a lower GSD has better resolution.

Emerging Trends and Technologies

AI and Machine Learning

AI algorithms can automate GSD optimization by analyzing terrain features and adjusting UAV parameters in real-time.

Advanced Sensors

High-performance sensors, such as LiDAR and hyperspectral cameras, complement GSD optimization by capturing additional data layers.

Integration with BIM

Combining UAV-based surveys with Building Information Modeling (BIM) enhances project visualization and collaboration.

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BIOGRAPHICAL NOTES

All authors work as part of the MULTIGEOMATICS team, Ghana, as resident Geomatic Engineers, with Richmond being the team Lead and Joseph as the CEO and founder. We all have experience and high interest in engineering survey. However, there are individual special interest as well.

Richmond has interest in Engineering Survey and CAD software.

Eric has interest in GIS and Remote Sensing

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