APPLICATION NOTE

AERIAL PHOTOGRAMMETRY

Photogrammetric Mobile Survey

VECTORNAV

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Abstract Surveying and mapping is required for a variety of applications, including agriculture, construction and GIS. Historically, surveying required usage of fixed ground stations and manual relocation of measurement targets. By utilizing techniques such as photogrammetry for mobile surveying, mapping can be done quicker and more efficiently. This note goes through the advantages of photogrammetry over other surveying methods, the practical implementation of photogrammetric surveying, and the impact of GNSS/INS on the photogrammetric process.

1 INTRODUCTION

Traditionally aerial photogrammetry imagery has been acquired with expensive satellite or manned aviation and applied to citywide or statewide projects. The emerging availability of post-processing software, coupled with improving digital camera and drone technology, has enabled accurate, fast, and affordable mapping capability of specific areas or objects. With tools available today, low barrier to entry has made photogrammetry attractive to use in various applications, including in construction, earthwork, agriculture, accident reconstruction, and 3D modeling.

Photogrammetry is the science of measuring distances, areas, and volumes in an environment through photographic images. Modeling requires capturing multiple pictures from different vantage points; then, post-processing software finds co-located features and applies triangulation to orient both the images and their features. Typical outputs are 3D point clouds and orthophotos.

Aerial and terrestrial photogrammetry are common but differ in purpose. In aerial photogrammetry, the camera is mounted in an aircraft while capturing overlapping photos of the area of interest. Aerial imagery applies in terrain modeling. In contrast, in terrestrial photogrammetry, the camera is located on the ground, either handheld, vehicle, or tripod mounted. It applies to model and measure buildings, engineering structures, and accident scenes. These applications are considered 3D modeling.

When making productive measurements of an environment, results should correspond to an absolute reference system that can integrate with other conventional measurement systems. In survey-grade measurement applications, the integration of accurate GNSS/INS is a requirement to geolocate images.

This application note highlights the advantages of using photogrammetry in measurement applications by comparing it to conventional measurement technologies. Later sections walk through the components and processes required to complete a photogrammetric survey and generate actionable information, with a focus on the GNSS/INS contribution. Please contact VectorNav for a more in-depth discussion of your particular application and the impacts of various design choices.

1.1 Alternative Surveying Techniques

To better understand the advantages of photogrammetric measurement, its alternatives should be considered. Traditional tools for precise terrain mapping include GNSS Surveying, Laser Scanners, Mobile LIDAR Surveying, and Total Stations, as discussed here and diagrammed in Figure 1.

GNSS Surveying

Terrain mapping can be accomplished with a pair of GNSS receivers: (a) the base receiver mounted to a tripod and located at a known reference position, and (b) the rover receiver on a monopod that is manually relocated to the desired measurement points. This method takes a long time and produces a minimum set of data.

Static Laser Scanning

Another technique in surveying and modeling is laser scanning, where operators set up a scanning laser over a known reference position, and use additional references in the sensor's field of view to produce a referenced point cloud. This method produces dense data points, but is limited to line-of-sight and is time-consuming to reposition when scanning large areas.

Total Station Surveying

Total Stations can also be used in surveying. These systems rely on optical instruments, a theodolite placed over a known location, and a reflective prism that is transported by an operator to measure points of interest, as in GNSS Surveying. Like laser scanners, Total Stations are limited to line-of-sight.

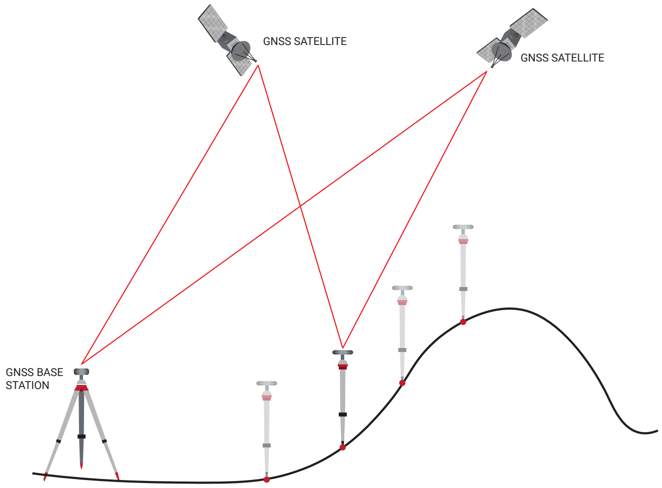
Mobile LIDAR Surveying

Mobile LIDAR is a fast and efficient measurement technique that uses light emitted from a sensor to measure its range to reflective objects. When integrated with GNSS/INS, the solution produces detailed point clouds, regardless of lighting conditions. More details can be found in Application Note AN205: LIDAR Mapping.

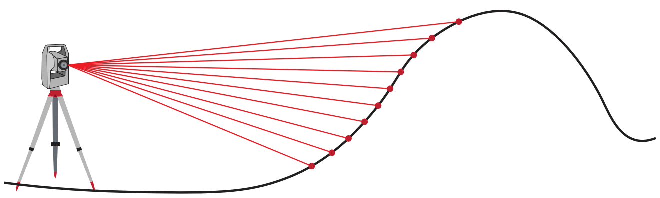
1.2 Aerial Photogrammetry

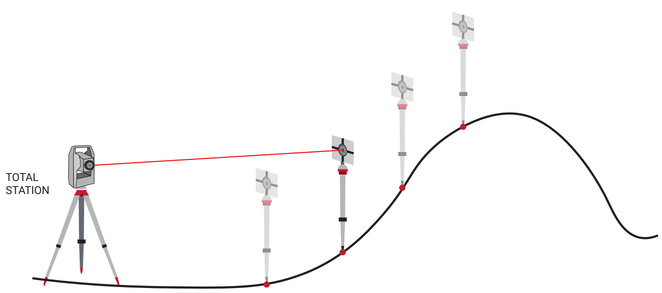
One of the most significant advantages of photogrammetry for measurement is the hardware's small size, weight, and power (SWaP). The essential hardware configuration requires only a camera for obtaining imagery and a standard GNSS for coarse georeferencing. The compact

Alternate Surveying Techniques



(a) GNSS Surveying


(b) Static Laser Scanning



(c) Total Station Surveying

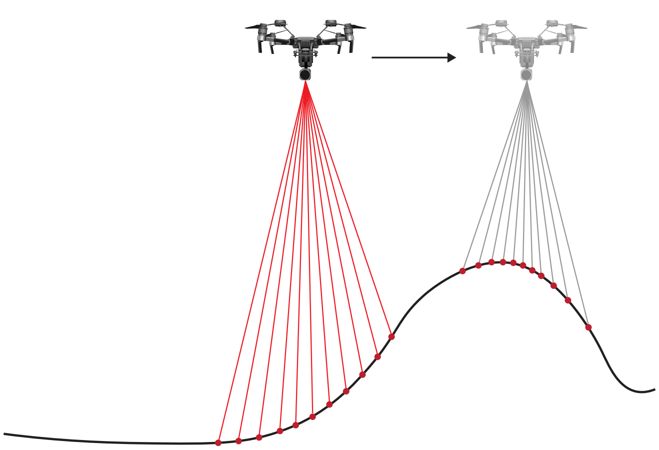
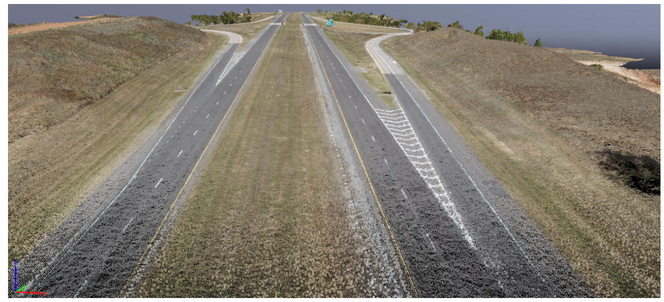
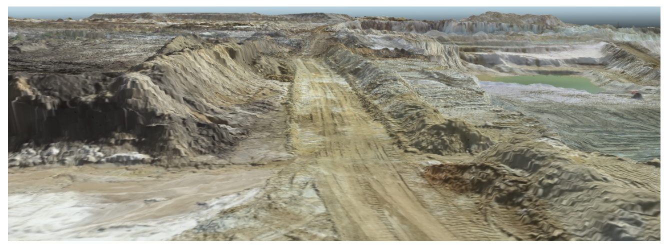

(d) Mobile LIDAR Surveying

FIGURE 1

Application Examples


(a) Road Construction


(b) Surface Mining


(c) Agriculture (Palm Farm)

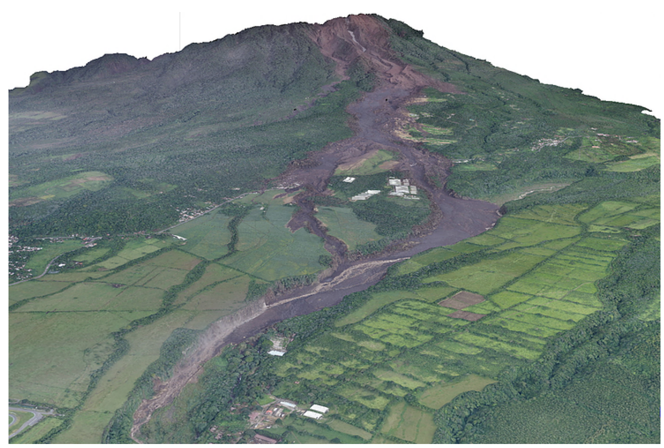

(d) GIS (Volcanic Eruption)

FIGURE 2

hardware configuration simplifies the system's integration into aerial and mobile vehicles. Optimized SWaP provides more opportunities to integrate into moving platforms that host the hardware. The small size and low power also imply a smaller burden and greater endurance for the navigating vehicle, providing a suitable alternative where vast areas need to be surveyed.

Photogrammetry Example

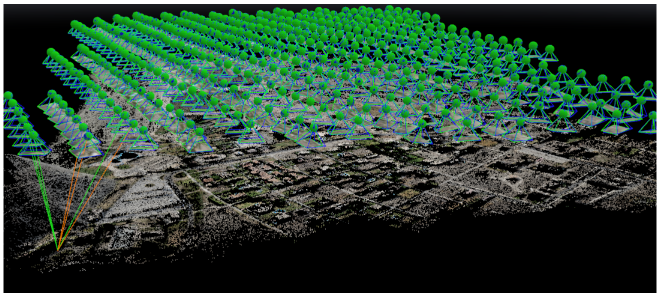


FIGURE 3

Contrasting with the traditional methods mentioned, photogrammetry yields spectral data in addition to spatial data. Most cameras provide images in the red, green, and blue bands, which are sufficient for many survey applications. In applications such as in agriculture, details about a crop's reflectance are measured by using application-specific bands.

Photogrammetry works well when its limitations are taken into account. Photography depends on lighting for acceptable image quality. In post-processing, high vegetation can introduce poor results when ground level is the expected measurement. Dense foliage also may prevent triangulation if sufficient key points can't be found between images.

1.3 Example Applications

Photogrammetry applications relate to objects or areas that need to be documented or measured where data can be gathered once or constantly to provide a closed measure and modify feedback loop. Some of the applications covered are in construction, earthwork, agriculture, and geographic information systems, as shown in Figure 2.

Road Construction

Road construction is an excellent application for aerial measurement. Since these projects usually consist of large areas or corridors, photogrammetry can reduce the time and cost to document and measure progress. Photogrammetry comes into play as soon as heavy vegetation has been cleared. As earthwork and construction progress, photogrammetry continually provides engineers with updates of the project, which can be used to anticipate problems and modify the design. This type of data is critical to maintaining schedules, speed up time to completion, and ensure a low deviation from design.

Surface Mining

Photogrammetry is one of the most efficient methods of measuring in earthworks. Surface mining operations require constant terrain measurements, earthmovers are regularly changing the landscape, and engineers need a closed feedback loop to understand how work is progressing. In mining operations, stockpile volumes, gradients, and fill volumes need to be known for inventory, safety, and business decisions. During the reclamation phase, engineers need to return the land to its original condition, requiring measurements to verify the work done. The low SWaP feature of photogrammetry is best appreciated in this vast area, high measurement rate application.

Agriculture

In agricultural applications, stakeholders are concerned with maximizing yields. Occasionally, spatial data can be used to help understand drainage and water flows, but more often, spectral data in red, green, blue, red edge, and near-infrared bands are used to study a crop. Agronomists use a plant's reflectance data to help find inefficiencies in the crop, enabling prompt decision making required to maintain the expected yield. Additionally, agronomists can also use the orthophoto produced by post-processing to determine their inventory. For example, in the case of the African palm plantation, the imagery clearly shows where cops need to be replanted. This information is challenging to obtain from the ground-based observation but is easily acquired from an aerial view.

Geographic Information Systems (GIS)

Geographic Information Systems (GIS) analysts use 2D maps and 3D scenes to estimate and predict, interpret and understand lending new perspectives to the decision-making process. Even though web-based mapping products are commonly available, these products may not be up-to-date or provide the proper licensing to use the data. The products produced by photogrammetry are ideal for providing proprietary, up to date information in GIS applications like urban planning, environmental impact analysis, and disaster assessment.

2 PHOTOGRAMMETRY BASICS

At a high level the process used for all photogrammetery surveying is similar: a camera is used to generate images, which are then referenced to some common reference frame. From there the referenced images are then post-processed and stitched together to form either a point cloud or orthophoto.

2.1 Cameras

Every photogrammetry solution must have a camera to acquire photographs. When selecting a camera, designers should consider the desired result: the point cloud and orthophoto. The range from the target to the camera and the camera's sensor resolution determines the resolution of the orthophoto. These parameters should be selected to sufficiently resolve the features of interest.

To determine where an image is taken while the camera is in motion, synchronization between the camera shutter and the GNSS is critical. There are many cameras on the market. Some cameras are available with shutter feedback; others provide flash signals on a hot shoe, while many provide no feedback and are difficult to integrate with GNSS.

Due to their imperfections, camera lenses distort the captured scene, and lens distortion can create alignment errors during post-processing. Therefore, when requiring the most accuracy, lens calibration must be taken into account. Lens calibration techniques exist in which checkerboard patterns are photographed, and then the images are analyzed to determine a camera's internal parameters. Professional photogrammetric post-processing software accepts calibrated internal parameters, including tangential distortion, radial distortion, affinity, and skew.

2.2 Stereo-Vision Processing

Photogrammetry generates a 3D point cloud through stereo-vision triangulation. The typical flight-track for a photogrammetric survey is shown in Figure 4, showing the substantial overlap between images – both along-track and cross-track – that allows for stereo triangulation.

Imaging Overlap

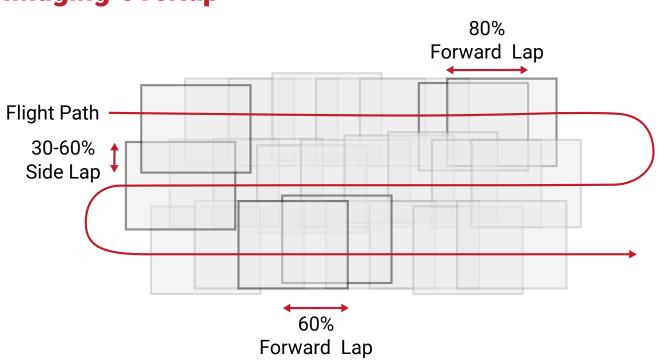


FIGURE 4

Post-processing software identifies unique features within each image and correlates them to the same features in overlapping images. The most distinct of these feature points are designated tie points or key points and allow for the determination if the position and orientation of the camera, as seen in Figure 5. With the positions and orientations of each image determined, a dense point cloud or orthophoto can be triangulated from the remaining overlapping features in each image.

Image Processing

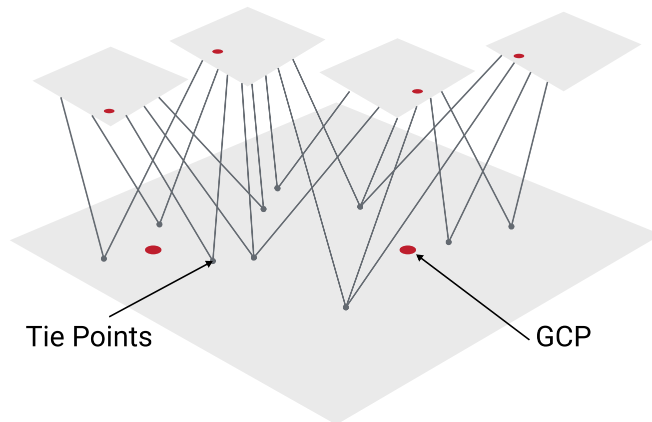


FIGURE 5

3 GEOREFERENCING POINT CLOUDS

One of the major considerations is the hardware used for mapping images to a common reference frame. Using ground control points (GCP) as a reference in the images is a common way to reference the images, however using GCP can be cumbersome and the accuracy of using GCP only can be limited. In order to improve on a GCP solution a GNSS receiver can be used on the imager. Optionally a GNSS-aided INS sensor can also be used as a coarse solution for processing optimization.

In cases where GCP is unavailable, unwanted or not precise enough, post processing kinematic (PPK) or real time kinematic (RTK) processing can be used to augment the GNSS solution such that GCP is no longer needed. In cases where the highest precision is needed, it is important to augment the solution using INS data from the imaging system as well proper calibration data for the imager lens.

3.1 Ground Control Points (GCP)

Accurate mapping can be accomplished without referencing the location of each image. However, ground control points (GCP) – visual references with known coordinates as seen in Figure 6 – must be established throughout the area of interest. The post-processing software that matches image tie points also matches these pre-surveyed GCPs to constrain the entire point cloud. This approach can be time-consuming by requiring manual work in setting up a scene with a sufficient number of GCPs.

3.2 Standard GNSS & Industrial-Grade INS

When choosing an INS for photogrammetry surveying the designer must decide between using an industrial or tactical grade INS to provide the necessary attitude precision. Representative performance values for each can be found in Table 1.

While it is not necessary to use a GNSS or INS solution for

Ground Control Point Setup

FIGURE 6

the most basic photogrammetry surveys using GCP, having at least a standard GNSS solution for the camera can greatly assist with georeferencing the images and overall accuracy of the survey. Furthermore the use of an industrial grade GNSS-aided INS can provide a coarse georeferencing solution for the images, speeding up post-processing and reducing the required image overlap and GCP density.

INS Attitude Error Values

ERROR SOURCE	INDUSTRIAL	TACTICAL
Yaw (σ_ψ)	0.3°	0.1°
Pitch (σ_θ)	0.1°	0.03°
Roll (σ_ϕ)	0.1°	0.03°

TABLE 1

3.3 RTK/PPK GNSS & Tactical-Grade INS

When GCP is undesired or unavailable, or, if greater accuracy is needed, higher performance GNSS/INS can be mounted to the imaging system to allow for an accurate direct georeferenced (DG) solution. In order to get a no-GCP solution, either RTK or PPK GNSS enabled GNSS needs to be used. The use of RTK or PPK GNSS can bring the position uncertainty from GNSS errors down to the centimeter range, as discussed in the following section.

The suitability of the INS orientation for DG is not only related to the precision of the attitude estimation (σ_a), but also the distance from the imager to the points of interest (d). This is due to the fact that the positional error ($\bar{\sigma}_a$) is calculated using Eq.1 and scales linearly with d.

$$\bar{\sigma}_a = d\frac{\sigma_a \pi}{180}[m] \quad (1)$$

4 PRECISE POSITIONING

As mentioned earlier, achieving centimeter-level positioning typically relies on one of two techniques: (a) Post-Processed Kinematic (PPK) GNSS positioning (offline), or (b) Real-Time Kinematic (RTK) GNSS positioning (online). Figure 7 shows the setup for an RTK system. In a PPK system, the real-time corrections from the base station are logged to a file rather than transmitted to the mobile unit.

4.1 Post-Processed Kinematic (PPK)

Since a real-time point cloud is not critical in most mapping and monitoring applications, a typical LIDAR solution is configured to produce an accurate point cloud offline using PPK techniques. The offline approach simplifies the operation of the sensor and improves the accuracy of the measurements.

Without the requirement to have a real-time link with the sensor, the operator is not constrained to communication limits between a GNSS base station and the LIDAR solution. The LIDAR's position can be determined in post-process using stored data from remote or local base stations.

Remote base stations like Continuously Operating Reference Stations (CORS) and virtual reference stations (VRS), facilitate the operator's workflow. CORS are permanently set up at known locations and monitored for accuracy and function, since their data is typically available for download, a user does not have to concern himself with the base station set up during his mission.

The highest positioning accuracy can be reached when post-processing GNSS and INS data by using precise satellite ephemeris data, which is not available in real-time. Forward and backward smoothing techniques can also be applied to improve the solution. Furthermore, without onboard computations to georeference a point cloud online, compact and low power hardware can be selected to record LIDAR sensor and GNSS/INS data. The post-processed approach reduces the size, weight, and power of the overall solution, which is especially critical in airborne applications.

4.2 Real-Time Kinematic (RTK)

It may be necessary to produce a point cloud in real-time, for example, to immediately ensure that the device is capturing the required data or to make immediate decisions based on current observations.

Configurations that require results without delay or minimal post-processing need to use RTK GNSS technology.

RTK Diagram

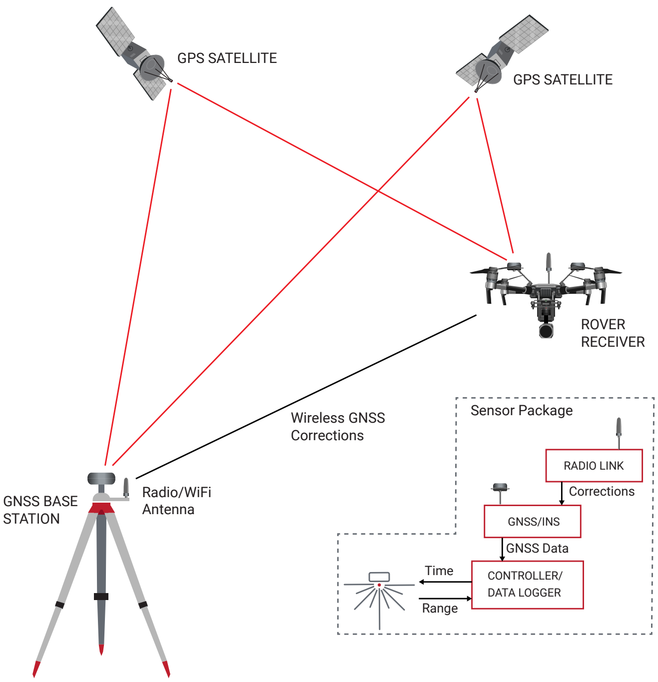


FIGURE 7

Contrasting with the PPK solution, an RTK solution needs a robust link between a GNSS base station and the mobile GNSS/INS in addition to the computational capability to reference each measurement from GNSS/INS data. The operator must have access to a correctly set GNSS base station with a radio link to the mobile GNSS/INS. However, the post-processing workflow is simplified as the point cloud is generated in real-time.

5 SOFTWARE PROCESSING

There are multiple options for inputs into photogrammetry post-processing software. The software accepts the images and their corresponding locations. If PPK GNSS is used, the PPK processing is performed separately, before supplying the image coordinate into the photogrammetry software. GNSS positioning must be time-aligned to the correct image file. The image/position data is then input as a separate text file or can be embedded in the image EXIF headers. Control points and lens calibration data is optional but generally beneficial.

A typical post-processing workflow starts by undistorting images if camera calibration data is available. Next, the software performs feature extraction, identifying key points as specific features in each image. A keypoint matching process then determines which images share the same key points. With the image set aligned, camera pose data can be optimized, and the model geolocated. Finally, a 3D point cloud can be created, followed by an orthophoto.

While 3D point clouds and images are the end products of a photogrammetric solution, this data is typically the starting point for generating actionable insights. Photogrammetric products are typically imported into CAD or GIS packages to provide base maps, surface, or model data. Engineers can then use their digital toolsets to measure volumes or distances and find differences in the measured environment. For large airborne data sets, intermediate software packages help simplify point clouds into line or surface drawings for compatibility with traditional CAD software, as seen in Figure 8.

Surface Model Output for a Valley

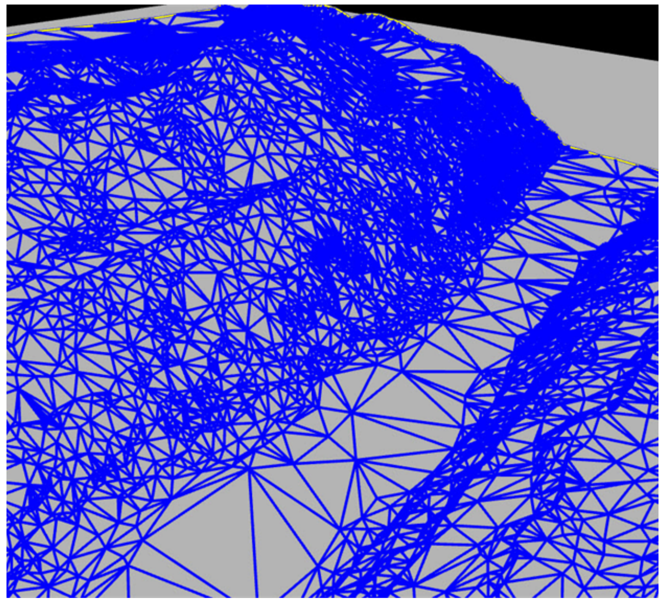


FIGURE 8

6 CONCLUSION

Advances in computing power, software, and digital cameras are attracting stakeholders in measurement centered applications to adopt photogrammetry. Precise photogrammetry relies on cameras integrated with high precision GNSS/INS in combination with post-processing software to create an optimized SWaP solution that can digitize vast areas when used on aerial vehicles. Careful consideration of component mounting, timing errors, and lens calibration can produce survey-grade mapping results that exceed traditional techniques in speed, safety, and accuracy.

VectorNav Technologies, LLC
10501 Markison Rd
Dallas, TX 75238, USA

Tel: +1.512.772.3615
Email: sales@vectornav.com
Web: vectornav.com

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