WHITE PAPER

Trimble VISION

Ken Joyce

Martin Koehler

Michael Vogel

Trimble Engineering and Construction Group

Westminster, Colorado, USA

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Trimble Engineering & Construction Group, 5475 Kellenburger Road, Dayton, OH 45424-1099, USA

Abstract

Trimble VISION technology integrates calibrated digital cameras with Trimble S6 and S8 total stations, as well as the Trimble VX Spatial Station. These instruments have the ability to collect survey data, stream video from the perspective of the instrument, and capture panoramic still images. Trimble Access field software overlays survey data on the streaming video, which enhances the surveyor's field productivity when operating the instrument robotically. Trimble Business Center office software overlays survey data on the captured panoramic still images, enabling the surveyor to efficiently document features that were surveyed. Trimble Business Center also enables the surveyor to make terrestrial photogrammetric observations and compute point coordinates using the Trimble VISION images. Trimble VISION photogrammetry is a survey tool that precisely measures points which were previously time-consuming, dangerous, or impossible to collect using other techniques.

Introduction

The camera in a Trimble VISION instrument captures millions of survey observations almost instantaneously. This whitepaper tells the story of how the pixels in streaming video and still images become survey observations through the integration of calibrated cameras with optical total stations. It then shows how surveyors can integrate precision imagery with observations from GNSS receivers, total stations, and 3D laser scanners to improve field operations, measure remote features using photogrammetry, and create realistic deliverables.

Trimble VISION Camera

The fundamental component of Trimble VISION technology is the calibrated digital Trimble VISION camera. The camera is designed to maximize quality by optimizing field-of-view, exposure, depth of field, resolution, and image file size. These design elements play a critical role when applying the photo technology to survey operations in the field and office.

Figure 1. Total station with Trimble VISION camera

Table 1. Trimble VISION camera specifications

Technical Specifications	
Focal length	23 mm (equivalent to 127-mm focal length for a 35-mm image format)
Fixed focus	12 m
Depth of field	3 m - ∞
Chip size	½" (4:3)
Resolution	2048 x 1536 = 3.1 Megapixel
Field of view	16° x 12° 28.5 x 21.5 m at 100 m
Zoom	4x digital
Frame update rate	5 fps in USB Mode

Field of View

Streaming video provided by the Trimble VISION camera always has a wider field of view than the instrument’s telescope view. This makes it easy to identify survey targets or features and use the video to aim the total station at them.

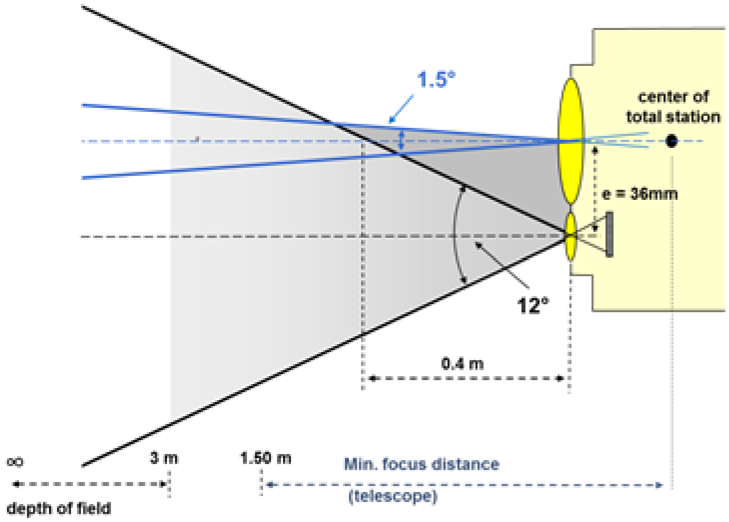

Figure 2. Maximizing quality by optimizing field of view

The following images compare the fields of view using four camera zoom steps. The telescope view is shown by the yellow circle.

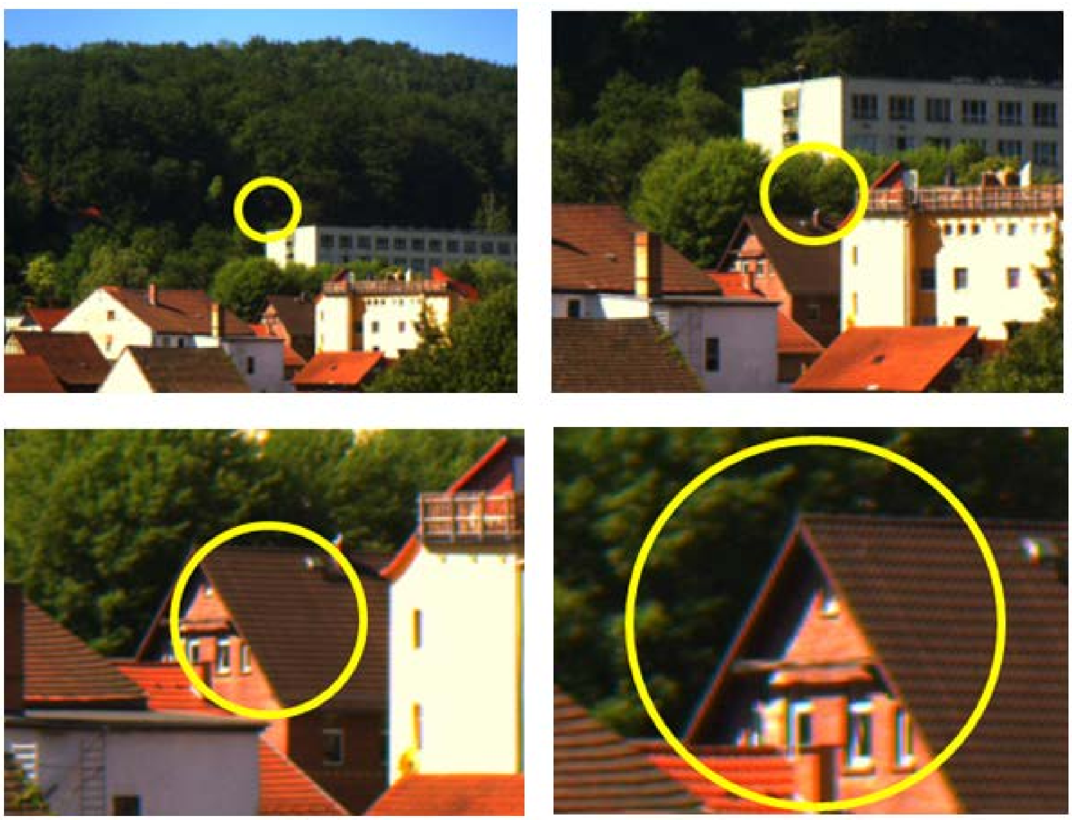

Figure 3. Fields of view using four camera zoom steps (yellow circle shows telescope view). The increasing zoom level is used to adjust the aim of the total station.

Exposure

To ensure that objects viewed in the streaming video and in still images are clearly identifiable in a wide variety of lighting conditions, the Trimble VISION camera automatically adjusts exposure for the object to which the instrument is pointing, as shown in the following figure.

Figure 4. Red box shows area used for exposure reading

For panoramic images, exposures can be automatically adjusted for each image, or they can be fixed at the optimal level for a single object.

The Trimble VISION camera also provides very good low-light sensitivity. The camera makes automatic adjustments in low light situations to maintain constant video quality. However, the video update rate may slow down, especially when operating the instrument robotically.

Depth of Field

Because depth of field for the Trimble VISION camera ranges from 3 m to infinity, objects of interest in the video stream and still images are almost always in focus. The following figure shows the advantage of large depth of field.

Figure 5. Shallow depth of field (top) and large depth of field (bottom)

Resolution

To ensure adequate resolution for clear viewing and manageable image file sizes, the Trimble VISION camera incorporates a sensor with a resolution of 3.145 megapixels (2048 x 1536) and a pixel size of 28 arc-seconds (that is, each pixel on the sensor captures 28 arc-seconds of the area being photographed).

Image File Size

To minimize the size of image files, and thus transmission time and storage requirements, the Trimble VISION camera stores images in JPEG format. For still-image captures, users can select the desired resolution and JPEG compression rates as shown in the following table.

Table 2. Trimble VISION camera image sizes and file compression

Image Size	
Format:	Pixels:
Extra Large	2048 x1536
Large	1024 x 768
Medium	512 x 384
Small	256 x 192
File Compression	
Setting:	Quality Reduction:
Super Fine	Approx. 10%
Fine	Approx. 40%
Normal	Approx. 60%

Images captured in the Extra Large size and Super Fine compression mode will have the highest quality, but will also require the most transmission time and storage space. A photo taken with these settings will have file size of approximately 700 KB.

This section has shown how the Trimble VISION camera captures pixels that are optimized for quality and efficiency. The next step is to integrate the camera into a total station in order to precisely relate the pixels to the real world.

Trimble VISION Camera Integration

This section describes how the geometric model for the Trimble VISION camera is combined with the geometric model for a Trimble total station to create a single calibrated system. The merger of the two systems enables the precise matching of survey data with video and still imagery.

Total Station and Camera Geometry

The following figure shows the basic geometric model for a total station. Where the vertical axis is (V-V), trunnion axis is (T-T, normal to V-V), and the sighting axis is (S-S, normal to T-T).

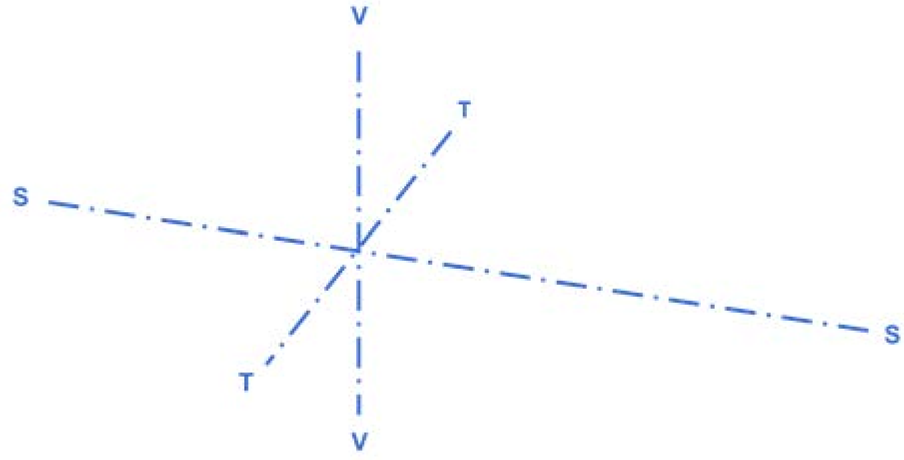

Figure 6. Basic geometric model for a total station

The next figure shows a simplified model of the Trimble VISION camera for the derivation of directions out of measured image coordinates.

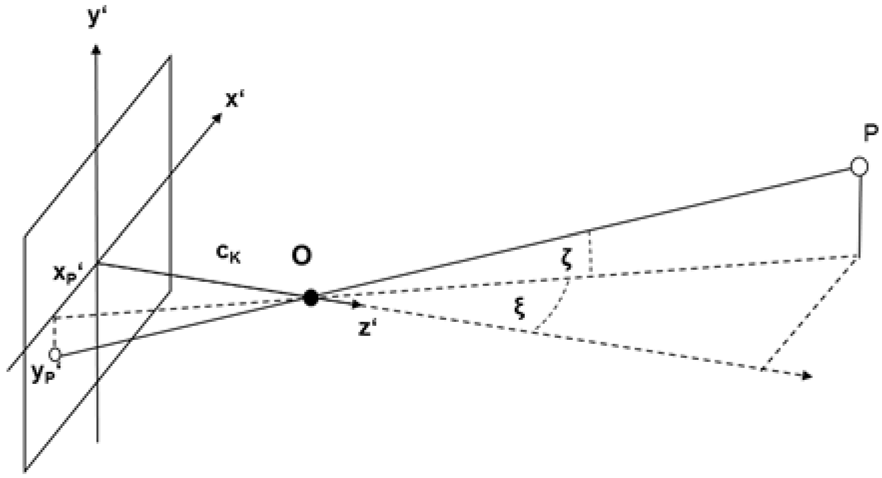

Figure 7. Simplified model of the camera

As this model shows, a point (P) is projected onto the image plane via the projection center O. The projection center (O) is the angular point of all directions. The angles ξ and ζ can be calculated from the measured image coordinates y' and x' and can be compared to directions measured with the total station.

The following figure shows a merged model wherein the camera is simply placed in the existing total station optics.

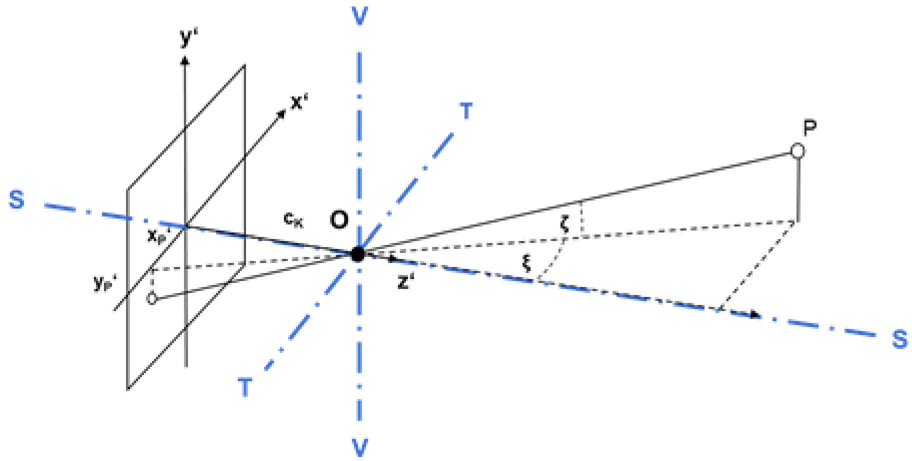

Figure 8. Merged model of total station and camera

This model shows that the image plane of the camera is vertical to the sighting axis of the total station. The Z axis of the camera system is in the sight axis, and the projection center is in the intersection point of total station axes.

When combined with the total station optics, this assembly has two major disadvantages:

- The camera has the same limited field of view as the telescope, which is not efficient for aiming.
- The telescope must be in focus to take a photo because the camera is located behind the focus lens.

Trimble VISION instruments use a more complex model in which the camera is independent of the telescope system, as shown in the following figure.

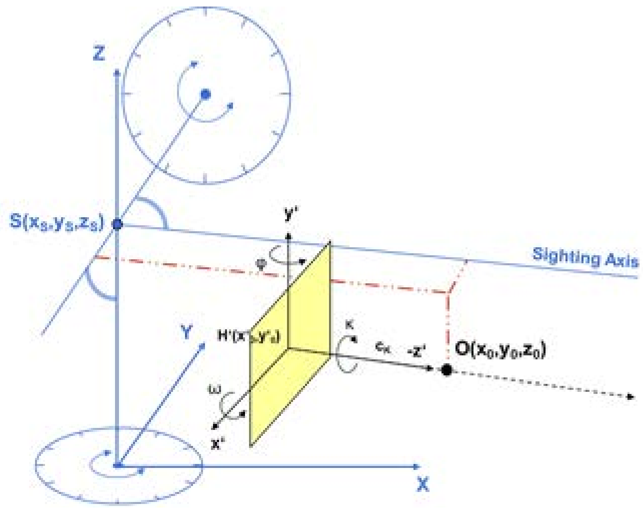

Figure 9. Camera independent of the telescope system

This configuration allows the camera to have a much larger field of view and a shorter focal length, resulting in better depth of field.

However, this biaxial setup creates eccentricity because the camera has a different perspective than the telescope. The eccentricity left uncorrected would create a difference in the views from the telescope and video. To correct for this, the Trimble VISION system solves for eccentricity in real-time using the electronic distance meter (EDM) tracking mode in the instrument to supply the distance.

Camera Calibration

The Trimble VISION camera lens and detector are calibrated using the interior orientation. The exterior orientation creates a complete photogrammetric definition, because it combines the camera with the total station axes and the total station measurements.

The parameters of the interior orientation are as follows:

- The camera constant ck (equal to approximately 23 mm)
- The principal point x’0, y’0. This is the point where the optical camera axis intersects the sensor array.
- Distortion

The parameters of the exterior orientation are as follows:

- Rotation angles: omega (ω), phi (φ), and kappa (κ) with respect to the camera axes

- Spatial offset: vector from the total station origin (the total station axis intersection point) to the camera projection center

From photogrammetric systems, we know the calibration can be done by measuring a field of control points. Because the camera is integrated with a total station, we need only two control points: the first at a distance of 3 to 4 m, and the second at a distance of 10 to 12 m. Each control point is measured with the total station (horizontal and vertical angle) and the camera (x' and y'). The angle and pixel observations provide sufficient information to solve for the unknown orientation parameters by a least-squares adjustment.

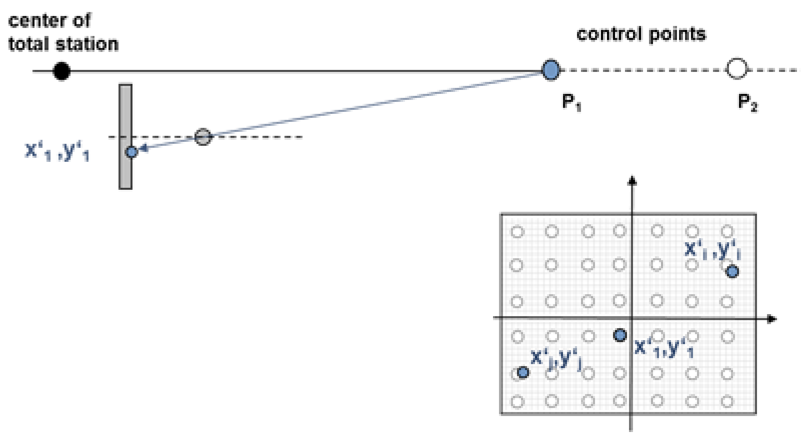

Figure 10. Calibration done by measuring a field of control points

The interior and exterior orientations complete the integration of the camera with the total station. Pixels can now be accurately translated to horizontal and vertical angles as if taken directly from the total station. The next section describes how the surveyor can apply the photogrammetry capabilities in the field.

Field Application

Traditionally, surveyors have been forced to look through the telescope of a total station to aim the instrument. This approach has been costly, challenging and potentially dangerous:

- One surveyor has to stay at the instrument.
- The instrument has to be set up at a low enough height for the telescope to be accessible.
- While aiming the total station with the telescope, the instrument operator may not be alert to immediate dangers, such as vehicle traffic.

Now, Trimble Access field software integrates with Trimble VISION instruments to improve these aspects of field operations and also control the capture of still images.

Figure 11. Trimble Access field software

Trimble Access displays live video from the Trimble VISION instrument. The surveyor can use the video to aim and operate the instrument entirely with a hand-held data collector or tablet computer. This enables the whole survey crew to work more productively and safely.

Figure 12. Trimble Access being used to remotely measure points in the field

The surveyor can use the video to remotely measure points with Direct Reflex (DR). The calibrated camera and precise integration with the total station allow Trimble Access to instantly and accurately transform pixels in the video display to horizontal and vertical angles. The surveyor can aim the instrument and measure points simply by tapping on objects in the video display. The same technology enables Trimble Access to accurately overlay cross-hairs and survey data on the video feed, so the surveyor can confidently collect points while avoiding such blunders as missed or duplicated measurements.

Figure 13. Trimble Access with overlay cross-hairs and survey data on the video feed

The surveyor can also use Trimble Access to collect still-images in order to report site conditions, document data capture, and even measure features in the office. Using the "Snapshot on measure" option, the field surveyor can automatically collect an image with every point measured. The still images are stored as Media Files or Attributes for seamless workflows in the office. In addition, the surveyor can capture multi-image panoramas with a user-defined overlap. For example, a panorama could be captured that completely covers the façade of a building.

Figure 14. Using Trimble Access to collect still-images

Trimble VISION images and field data can be streamed to the office using Trimble AccessSync, or they can be transferred manually. Once data is available, a surveyor in the office can continue the survey workflow using Trimble's desktop application, Trimble Business Center.

Office Application

Trimble Business Center (TBC) imports images captured by Trimble VISION instruments and displays them in 3D perspective "station views." The imported images are integrated with GNSS, total station, and other survey data, enabling the surveyor to document field data and measure points using photogrammetry.

Documentation

TBC's station views recreate the project site as it was seen by the field surveyor. Survey data, such as points and observations, are overlaid on the aligned images. The extreme care taken with camera technology and integration nearly eliminates discrepancies between the images and the survey data. Therefore, the surveyor can confidently use this tool to review the comprehensiveness and accuracy of the survey. For instance, the surveyor may identify areas of missing information or points that do not conform to a surface because of a field blunder. Or, the surveyor can use the station view to provide proof that required data was captured and done so precisely.

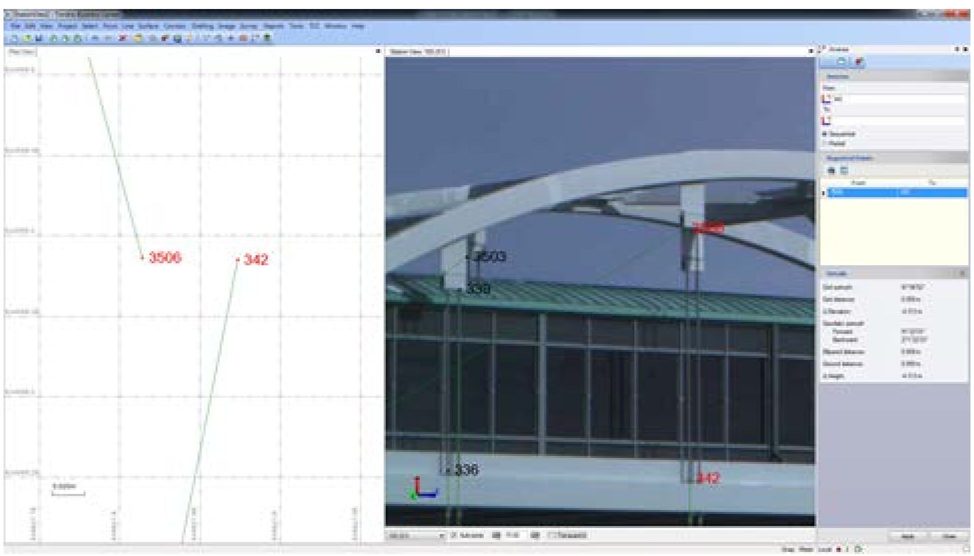

Figure 15. Plan View and Station View tabs in Trimble Business Center

To capture the images in a panorama, the camera in a Trimble VISION instrument must move horizontally and vertically about the center of the instrument. Because the camera changes position, each image has a different perspective. This difference in perspective creates "data parallax," which prevents images being viewed in TBC from aligning correctly with overlaid survey data. To control this, TBC shifts the perspective of each station view from the instrument's center when zoomed-out, to the camera location for a single image when zoomed-in. In addition, the user can control the projected distance for each panorama to "focus" the data overlay. Given these capabilities, survey data is always displayed in the most realistic-looking manner.

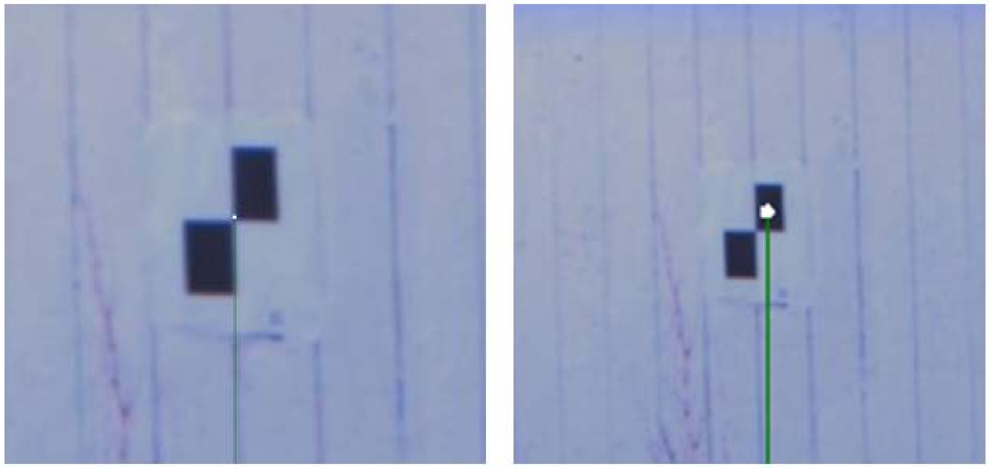

Figure 16. Example of data parallax: the left image of a target shows the camera perspective (zoomed in); the right image shows the instrument perspective (zoomed out)

To improve documentation quality, TBC can balance image exposures and blend the edges of adjacent images to give the appearance of a single, seamless panorama. The processed panoramic images, along with survey data, can be delivered in a single file and viewed using Google Earth's Street View.

Figure 17. Unprocessed images (left); balanced and blended images (right)

Photogrammetry

Surveyors can now measure points in TBC with images captured by Trimble VISION instruments. Photogrammetric point capture is precise at close range, and the surveyor can use this tool to improve efficiency and safety of data capture. For example, the surveyor can photogrammetrically measure the locations of power lines that are very difficult to measure with other survey techniques such as Direct Reflex (DR) or angle intersections.

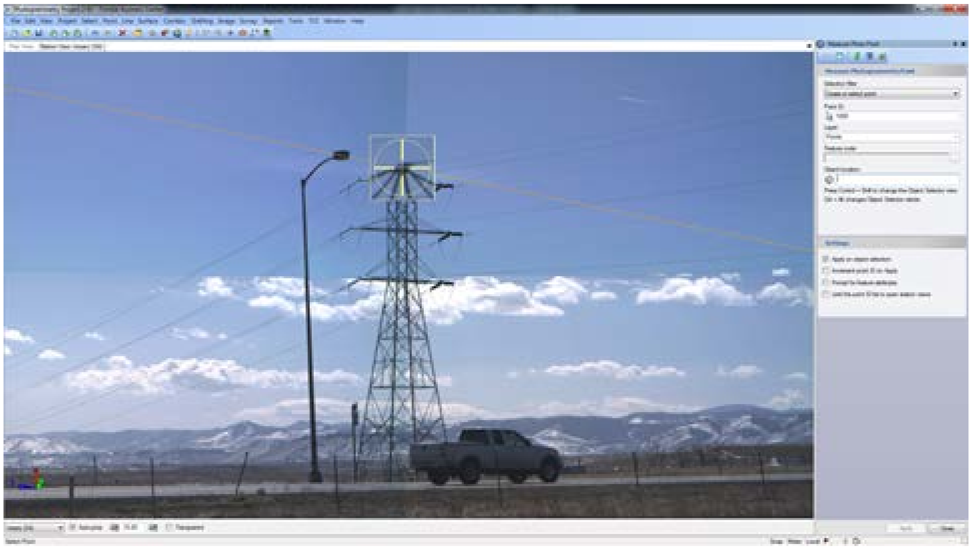

Figure 18. Using photogrammetry to measure objects that are difficult to measure in the field

Due to the careful and precise integration of the Trimble VISION system, the process of measuring photogrammetric points is simple. The surveyor finds an object of interest displayed in each of two or more TBC station views and uses a virtual telescope to select the exact image pixel in each view. TBC automatically calculates a 3D point from the intersection of the photogrammetric observations. The surveyor is then provided with indications of the quality of measurement, including the strength of figure (*see note below) for the intersection and residual values between the calculated point and each observation.

The following diagram shows the effect of geometry when using two observations to make a photogrammetry measurement. The quality of intersection geometry is shown for three typical examples:

1. Best Case: intersection angle of 90°
2. Long distance relative to baseline
3. Large eccentricity to baseline

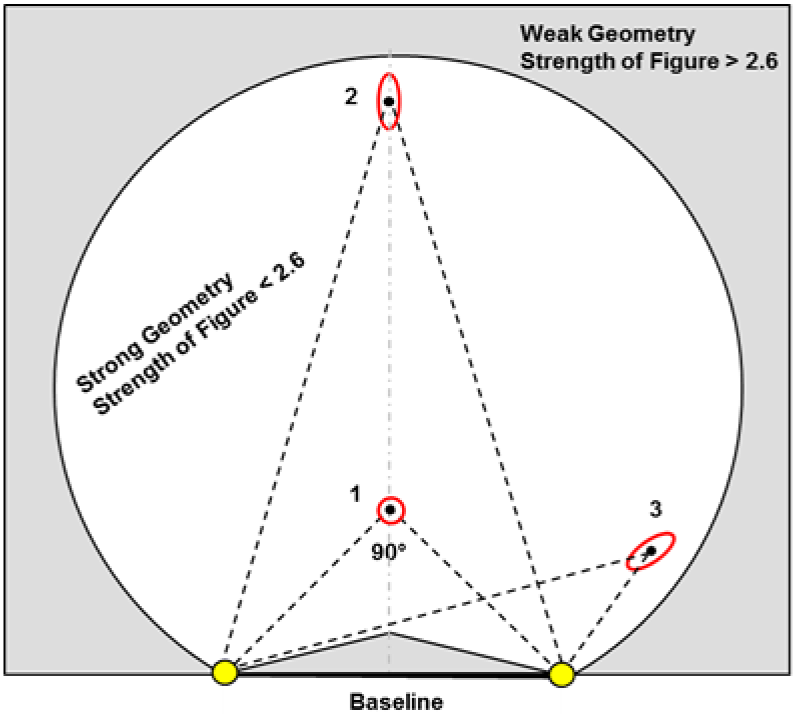

Figure 19. Areas of strong and weak geometry when using two station setups

Factors that affect the precision of photogrammetric point measurements are mainly within the control of the surveyor. As with any survey observation, precision degrades as distance increases. At close range, individual photogrammetric observations are more precise because each pixel covers a smaller space, and the effects of poor geometry are minimized. The best results can be achieved by measuring points at close range from stations with good positions, orientations, and geometry.

Given proper practice, surveyors can use the images from calibrated Trimble VISION instruments to accurately measure and comprehensively document survey points. The power of this system is evidenced by the extreme efficiency in measuring points photogrammetrically, where just a few images captured in the field with Trimble Access can be used to measure many points in TBC.

* "Strength of figure" is a system used to measure the accuracy of geometry for photogrammetric intersections. Intersection angles near 90 degrees are optimal and correspond with small strength of figure values. Large strength of figure values correspond to intersection angles less than 30 degrees or greater than 120 degrees. Strong geometry is a key element to achieving precise measurements, especially as distance from the baseline increases.

Conclusion

Precise imaging is a highly promising technology within the expanding tool-set available to surveyors. Currently, streaming video and still-imagery greatly increase the efficiency and safety of field operations. Field surveyors can now operate instruments in new ways, and they can show project members the exact conditions on a project site along with the accurate locations of data that was captured. And more than ever before, images can be used to deliver survey data in ways that are stunningly realistic.

Furthermore, recent developments in Trimble Business Center allow surveyors to measure points using photogrammetry. The true strength in photogrammetry is realized in the millions of pixels captured nearly instantly in the field; where pixels in Trimble VISION images are equal to horizontal and vertical angle observations. Now that this technology is available to surveyors, it is likely there will be a change in how surveys are conducted when measurements are difficult to make or the time to capture field data is very limited. For instance, a field surveying crew can quickly capture photos of a cellular phone tower. Then a specialist in the office can measure the locations, dimensions, and alignments of the antennas. Likewise in forensics, photographs of a scene can be captured very quickly onsite. Then the time-consuming process of extracting information can occur at any later date in a different location.

Current limitations in the imagery workflow include large pixel sizes, overly-manual extraction processes, insufficient data storage capacities, and slow computing speeds. These shortcomings limit the extent to which imagery can be used in surveying. But each of these issues will be overcome by the ongoing advancements of software and computing technology. Pixel size will decrease as camera resolution increases, resulting in improved precision. Field and office computers will have faster processors, more memory, and more storage capacity, resulting in improved efficiency. And software features such as image processing and analysis will improve the power of the entire workflow.

Equally important to advances in technology is a strict dedication to make photogrammetry an accessible tool to the surveyor. Here, Trimble has taken the first steps by integrating photogrammetry with traditional survey applications. Surveyors can easily master this tool and use it to measure the world in a whole new way.