TopoDOT™ Tech Notes

Certainty 3D

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To: General Release

From: Ted Knaak
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Re: TopoDOT Calibrated Image Terrestrial Mobile (#1003)

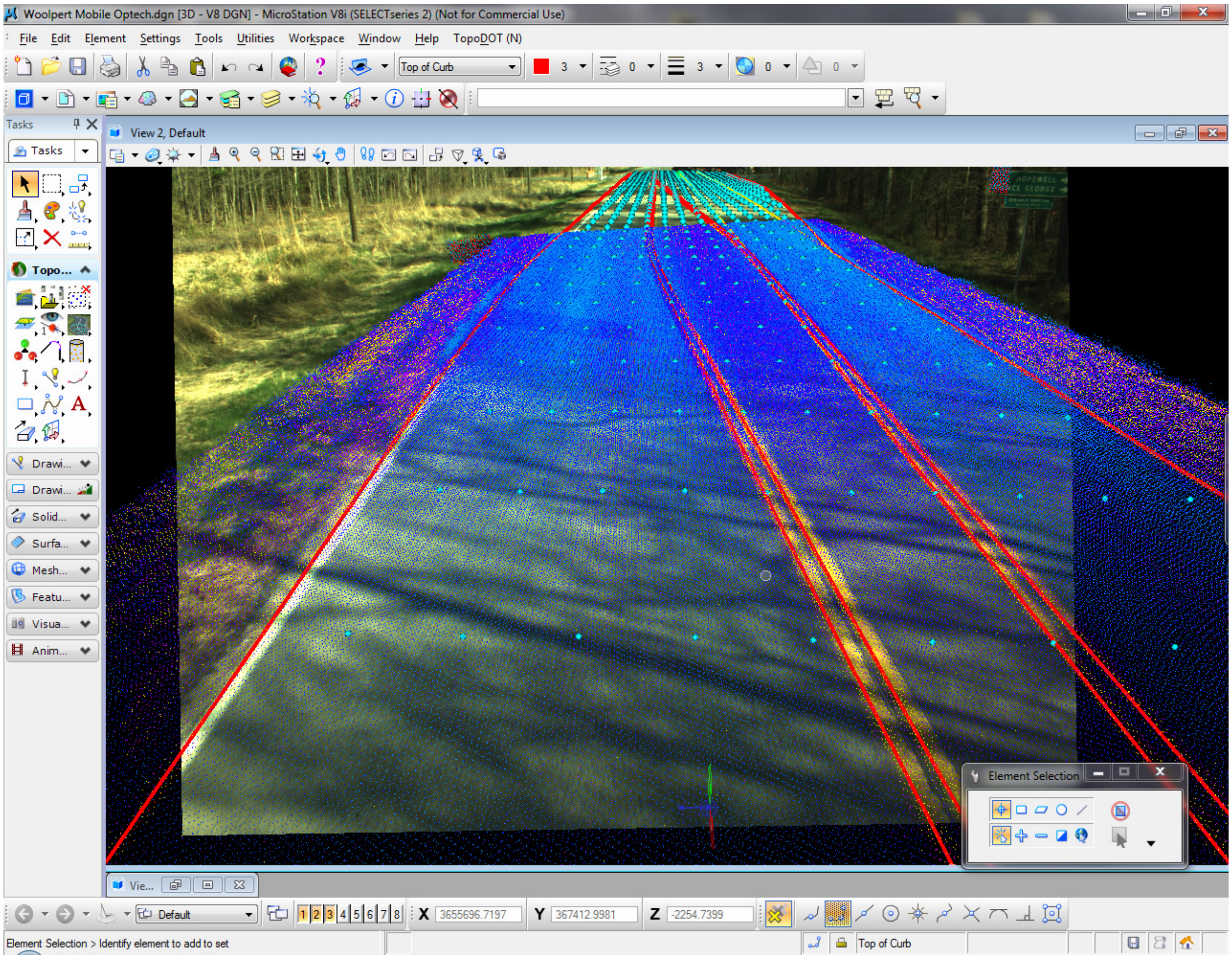
Background

The TopoDOT® application offers the capability to import calibrated images and map the image pixel orientation to the perspective view of the selected MicroStation™ view. This unique tool makes it possible to overlay extracted CAD elements over the image in the selected view with very high precision thereby employing this image information as a reference in feature identification.

TopoDOT® places specific requirements on the calibrated image if this feature is to be successfully employed. This document identifies and explains the calibrated image and associated metadata requirements for terrestrial mobile systems necessary for effective application of this unique TopoDOT® feature.

Example

In the example below, extracted CAD elements are mapped to image perspective view very accurately. In order for TopoDOT® to map the image to the MicroStation™ perspective view, certain metadata and specific information must accompany every image and be accessible to TopoDOT®. Note that in addition to the MicroStation™ elements, the raw point cloud data is also mapped to the MicroStation™ camera view perspective.



CAD Elements, Calibrated Image and Point Cloud

Requirements for Effective Application of Calibrated Images in TopoDOT®

In order to accurately map images to the perspective view of the CAD view, the camera/lens taking the image must be calibrated. It should be noted that no two camera/lens pairs are quite the same and therefore should be calibrated individually.

Note that the calibration procedure takes place outside of TopoDOT®. Camera/lens calibration is the purview of the individual system vendor. TopoDOT® requires only specific metadata information from the calibration process. This metadata must be accessible within the project deliverable with lineage to each calibrated image. Finally, the performance level of the mapping operation in TopoDOT® will only be consistent with the quality of the image calibration model, alignment and associated metadata.

Image File Format

The preferred calibrated image format for TopoDOT® is .jpg, however other standard formats can be accommodated.

Camera/Lens Calibration Model

Images must be accompanied by a documented camera/lens model. This model must be available to TopoDOT® for import with the images. Detailed documentation of the camera model describing the application of each parameter is also required. Such a camera model facilitates the mapping of CAD elements to image pixels accounting not only for the basic camera model, but tangential and radial distortion of the lens.

Below is an example of camera model parameters for a terrestrial mobile mapping system and the accompanying documentation. (Note: Information courtesy of Woolpert, Inc. www.woolpert.com)

Camera Calibration and Orientation

Static Camera Parameters

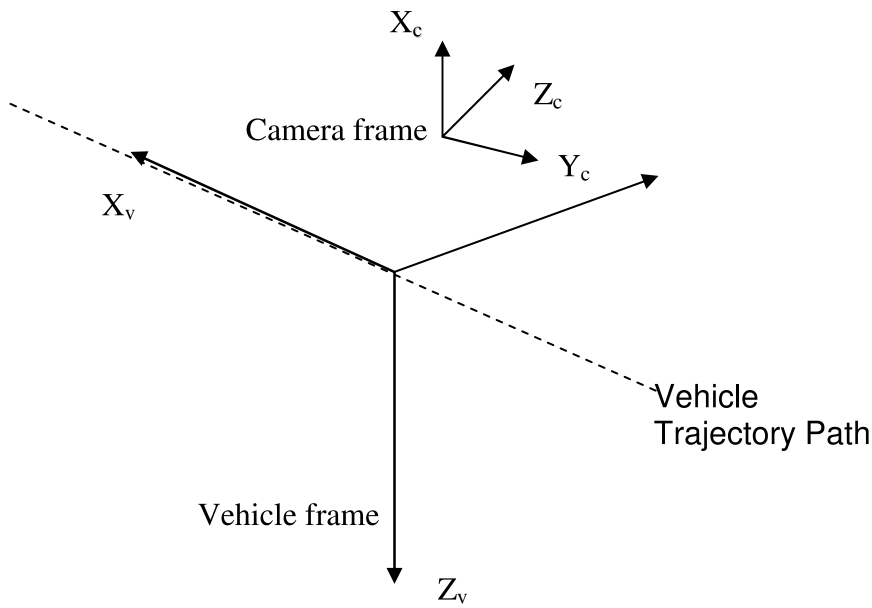
Static camera parameters are those defined with respect to the vehicle coordinate frame. Barring any anomalous movement within this coordinate frame, these parameters should be constant over all the images after a specific camera mounting. Keep in mind that dismount and remount of a camera might necessitate additional static parameter sets given changes in orientation.

The following information was provided courtesy of Woolpert operating an Optech Lynx system. The following set of parameters describes a specific camera. There should be one such set of parameters per system camera.

[Camera calibration and orientation]
Version=20050513
Description=
TimeOffset= 0.0000
Exposure= 0.00000
LeverArm= -1.2467 -0.5577 -0.3642
AntennaToCameraOffset= 0.0000 0.0000 0.0000
AttitudeCorrections(HRP)= -178.7604 -0.7253 -20.0092
PlateSize= 2456.00000000 2058.00000000
ImageSize= 2456 2058
Margin= 0
FiducialRadius= 40
FiducialMarks= 0
Orientation= SIDE
PositionFromGround= 3.890
RectifyCenter= 10.0

PrincipalPoint(XoYoZo)= 0.72290000 14.74028000 -2390.85142857
LensA3=-1.972250E-008
LensA5=4.501875E-015
LensA7=-0.000000E+000
LensP1=0.000000E+000
LensP2=0.000000E+000

The highlighted parameters are of primary importance to TopoDOT®. Their significance is explained as follows. Typically a mobile system coordinate frame is defined as a right-handed coordinate system with the X axis in the forward direction of travel, the Z axis down, and the Y axis orthogonal to X and Z. Rotation around X is called "roll", around Y is "pitch" and around Z is "heading".
Camera location and orientation within the vehicle frame as well as its distortion model must be precisely known in order to accurately map image information into TopoDOT®.



Lever Arms – These are the offsets from the vehicle origin to the center of the camera coordinate system. (These parameters may or may not be of direct value to TopoDOT depending on whether the camera position is given or just the trajectory position for each image.)

Attitude Corrections – These three angles describe the rotation of the camera mounting position with respect to the vehicle frame. The order of rotations is important and should be documented.

Orientation – Cameras are often mounted on their side thereby rotating their coordinate frame about the "camera" Z axis by 90 degrees.

Principle Point – In this example, the principle point Xo Yo is the location of the optical axis in pixels, where Zo is the focal length in pixels.

Lens Parameters – These parameters describe the radial and tangential distortion of the camera/lens pair.

Dynamic Camera Parameters

The following parameters represent the time synchronized parameters which associate each image with a position and vehicle orientation in a project coordinate frame.

The following example from this mobile system shows the parameters associated with "each" image. This system ran two cameras, identified as "Cam1" and "Cam2" in the filename and Camera=0/Camera=1 as the index.

```
[TerraPhoto image list v5]
Image=survey3_Cam1_000506.jpg
Time=504292.728785
Xyz=3652421.287 370389.279 62.600
Hrp=302.34758 -0.14006 -0.30863
Camera=0
Quality=1
Color=C0;0;0;0;0;0

Image=survey3_Cam2_000508.jpg
Time=504293.778907
Xyz=3652384.111 370418.155 62.451
Hrp=301.43456 0.72576 -0.39011
Camera=1
Quality=1
Color=C0;0;0;0;0;0

Image=survey3_Cam1_000512.jpg
Time=504295.729027
Xyz=3652309.617 370458.696 62.348
Hrp=300.35658 0.20770 -0.35023
Camera=0
Quality=1
Color=C0;0;0;0;0;0

Image=survey3_Cam2_000514.jpg
Time=504296.779155
Xyz=3652269.621 370487.742 62.304
Hrp=300.78289 0.42901 -0.00045
Camera=1
Quality=1
```

Color=C0;0;0;0;0;0

Image – This is the file name for the specific image taken at this time along the trajectory. Standard .jpg format file is typical.

XYZ – This is the “camera” origin position along the trajectory (synchronized by “Time”). These coordinates, XYZ, are Easting, Northing, and Elevation. Note that since the camera “origin” position is given, thus the lever arm offsets in the camera static parameters are not needed by TopoDOT®.

HRP – These are the heading, roll and pitch orientations of the “vehicle” at this trajectory location.

Collectively these parameters prove sufficient to enable TopoDOT® to import the images into MicroStation mapped to the same perspective view as the CAD elements and point cloud data.

Suggested Project Requirements for Calibrated Image Data

This is a functioning example of calibrated images produced by a terrestrial mobile system and imported into TopoDOT®. It is by no means the only example and C3D had no intent of constraining any vendor in their approach to this implementation. Furthermore there is no mention of how these parameters are computed or of the processes by which these calibrations and computations are implemented and executed. Those remain the sole responsibility of the system vendor and/or operator.

What C3D can offer is a “suggested” approach to writing specifications or requirements for such data assuring successful importation into the TopoDOT® environment.

Development of Requirements Statement

<u>Step 1: Camera Performance Specification</u>
C3D would suggest requesting image samples taken of typical features of interest at the expected distance and angle in your project from one or more systems for your review. Determine the minimum acceptable resolution of the digital image sufficient to recognize features important to the success of your project. One would also expect some mention of proper exposure, contrast, etc. to identify features of interest.

<u>Step 2: Camera Model Specification</u>
C3D would suggest that a camera model containing at least the:

- Principle point
- And lens distortion model and parameters

for each camera/lens pair are provided along with relevant metadata. Keep in mind that this model will be different for each pair and “may” change if a lens is removed and replaced. Therefore the metadata should include camera and lens serial numbers, date of calibration, etc.

Step 3: Camera Mounting Specification (static)
The camera position and orientation within the vehicle frame are described by the lever arms and roll/pitch/heading angles (Lever Arms, Attitude and Orientation parameters described above in static parameter section). Note that these static parameters should not change after a camera is mounted. However they may change each time a camera is mounted to the system frame. Therefore these static position and orientation parameters should have lineage to associated metadata describing:

- Date and time of camera mounting
- If a calibration procedure was initiated—or not
- The calibration alignment results

Step 4: Dynamic Parameters
The relevant dynamic camera parameters basically describe the vehicle position and orientation at the time the picture was taken. Thus each image has a unique set of dynamic parameters.

The terrestrial mobile system will synchronize the camera trigger and record the GPS time very accurately. System processing software which calculates the trajectory parameters for each image estimates the trajectory location and orientation at this time typically through interpolation. Note that interpolation is necessary as the typical IMU is only about 200hz.   Based on these angles and location TopoDOT can place the image properly into the same perspective view as the point cloud and CAD elements. Suggested metadata associated with these values might be some general IMU information:

- IMU Type with relevant performance specs
- Last calibration and certification

Step 5: Documentation
This last step is directly applicable to the preceding four. Along with these parameters and metadata, the definition and order of coordinate transformations implied by these rotations must be thoroughly documented. Each defined coordinate system employed to transfer the images from the camera system to the project frame should be defined and illustrated. One or more detailed examples of the transformation sequences and corresponding calculations should accompany the data.

Another document requirement might be that all images within the project are properly stored and archived such that the lineage between each image file through the appropriate parameters and metadata is obvious and clear.

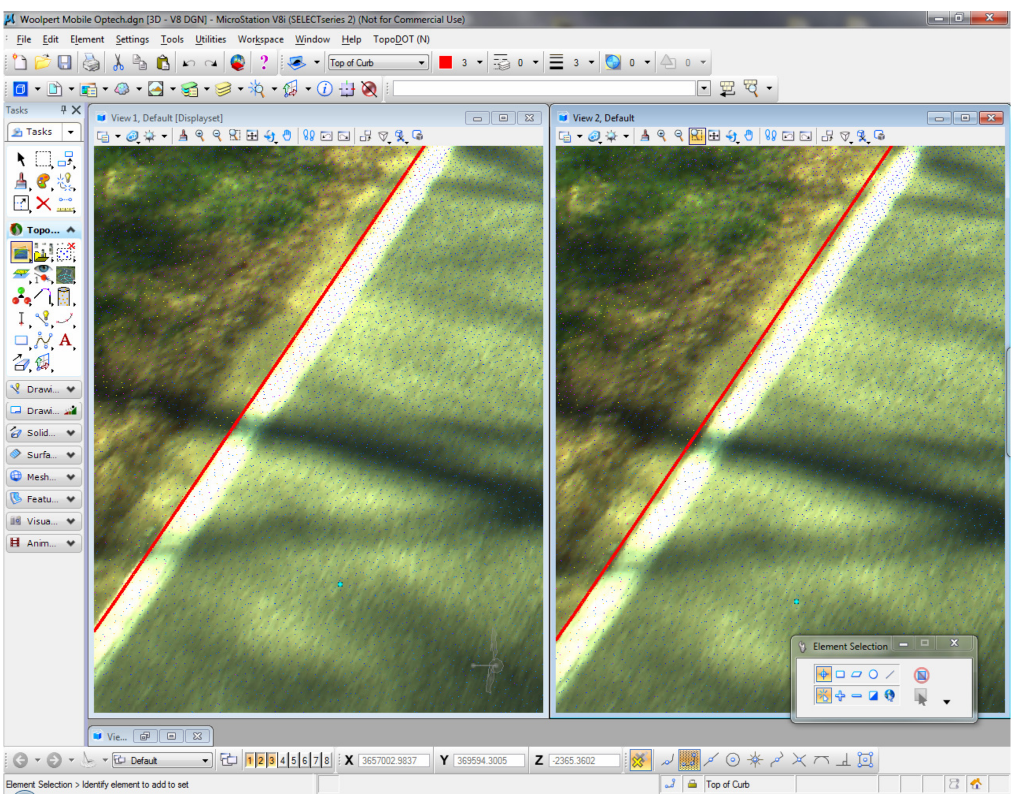
Step 6: Verification Process
Finally the system provider and purchaser of the data should agree on a verification procedure to assure that the information provided with the images was performed to some image alignment specification. The specification can be relatively simply stated as:

Sampling of a select number of images at random from the project shall consistently show the alignment of the images to CAD elements and point cloud data to be within X pixels one sigma. Note that a distance to camera requirement that is reasonable for the project should be included also; say 20-40 feet or so for typical mobile scanning projects along transportation corridors. Work with you vendor to agree on a reasonable distance for the system and project.

Verification of Image Alignment Using TopoDOT

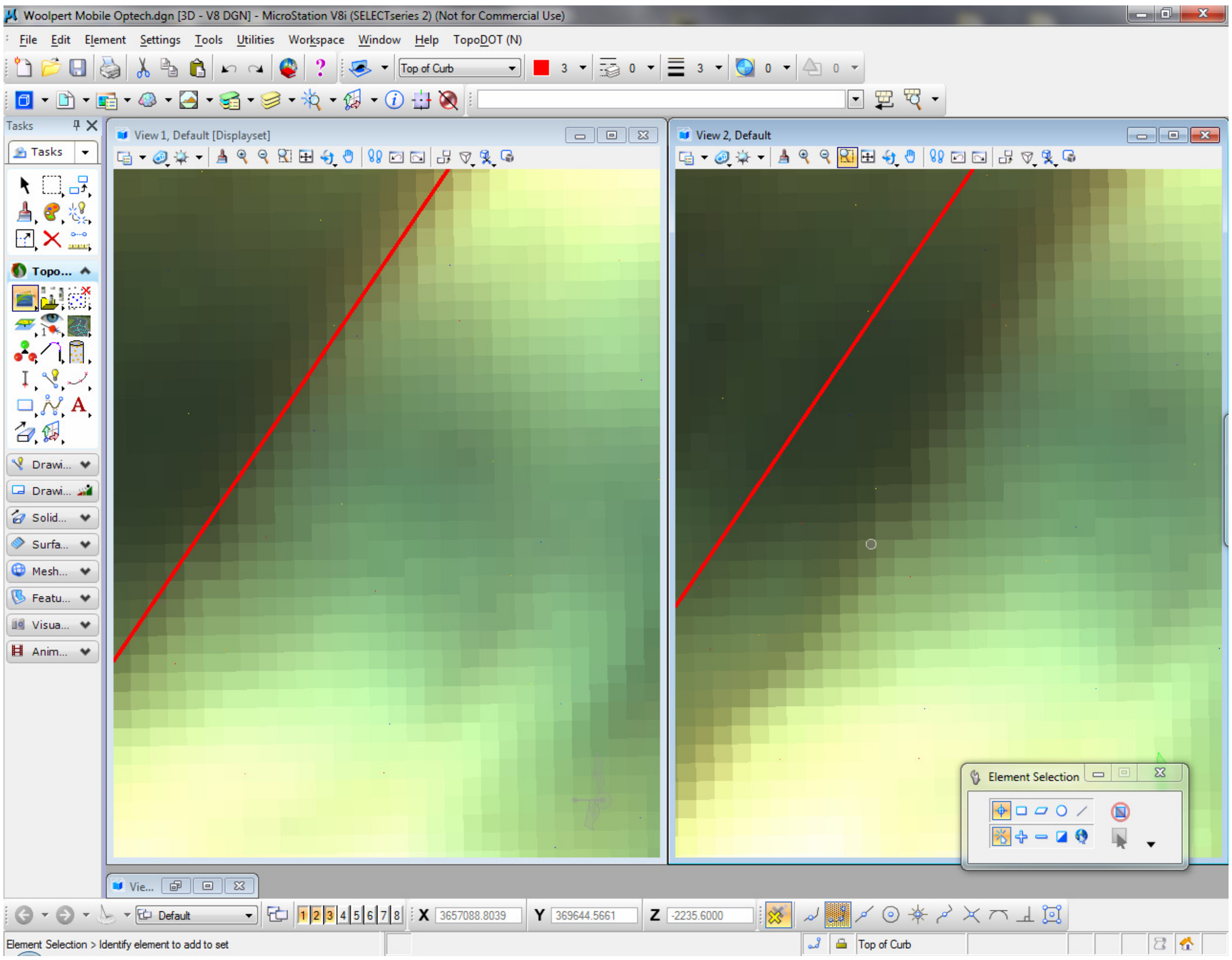
Verification of image alignment using TopoDOT® can be achieved relatively easily. Keep in mind that TopoDOT® will import spatial lidar data, point clouds, along with the calibrated images and place the images at the correct spatial location using the aforementioned parameters and executing the corresponding transformations. So the question is simply, “Is the image aligned?”.

We recommend using TopoDOT® tools to identify and extract linear features from the point cloud. For example, the corner of a building with points on intersecting walls can typically be very accurately identified and extracted. The resulting vertical line can then be easily compared to the corresponding image. The horizontal distance in pixels from the image building corner and the line indicates the misalignment of the image within the project (point cloud) coordinate system in the horizontal direction. Similarly, a horizontal linear feature can be used to indicate misalignment in the vertical direction.



Consider the example above using data from a terrestrial mobile system producing point clouds and calibrated images. TopoDOT® was used to extract the centerline of the road from the point cloud. (Point cloud elements colored according to amplitude return were used to identify the painted line among the road points.) The left image shows excellent alignment between the image and the data as the extracted CAD element is clearly within a pixel of the image line.

In order to illustrate a camera misalignment, we simulated an image misalignment by adding 0.02 degrees to the Heading Attitude correction parameter as shown in the right image. A close of the resulting transformation in TopoDOT® demonstrates that one can actually measure the image shift. In this case the line was shifted by about a 7 pixels in the image on the right.



Repeat this verification process for randomly selected images and features in the project and one should get a good sense of the alignment performance of the system. This illustrates that TopoDOT® can be used in a practical way to verify image alignment.

Finally, one should note that identifying a misalignment in TopoDOT® does not indicate the source of the misalignment. Linear misalignments such as in this example manifest themselves as a simple shift. Camera distortion model anomalies may show a more non-linear misalignment over the entire image. If the end-user finds consistent misalignments exceeding the requirements as stated above, the source of the error must be identified by tracing back through the system parameters, then resolved and image positions and mapping recalculated. *The reason for all the parameters, associated metadata, and corresponding documentation is then quite clear.*

This technical note shows how TopoDOT can be rather easily employed by the data end-user to verify that the quality of the delivered data will indeed meet expectations and be useful for its intended purpose.

Questions and/or Comments

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