Image-Based Modeling Workflow for Paleoseismic Trench Photomosaics

This document describes the process to create a structure-from-motion image-based model (IBM) of a paleoseismic trench exposure, from field to final logs, using Real Time Kinematic Global Positioning System (RTK GPS), a total station, Agisoft PhotoScan Professional Edition v.1.1 (PhotoScan), and GIS. This workflow is designed as a "best practices" case when a high level of accuracy is desired; however, this workflow should be customized for each trench. We added suggestions for some of the steps, but note that we have not always tested these in the office or in the field. The minimum tools required to make a scaled 3D model of trench are a small camera and a tape measure.

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Field Workflow

1. **Record azimuth (orientation) of the trench walls.** (optional)
   Record azimuth in degrees (0–360º) with a compass. This information is necessary for the provided script to export the photomosaic in a vertical plane with a look-direction orthogonal to the trench wall.

2. **Use RTK GPS to survey backsight points and tripod locations.**
   Create backsight points around the trench site for total station set up, and choose the total station tripod sites. Use RTK GPS to record coordinates of the backsight points and the tripod locations in an absolute coordinate system (e.g. Universal Transverse Mercator [UTM]).

3. **Set a grid of nails in the trench walls.**
   We use the total station to make a 1 m × 1 m grid of nails. Each nail is labeled with its relative trench coordinates (e.g, 19H 5V) on white duct tape. This replaces the need for a string grid.

4. **Record coordinates of nail heads to use as ground control points (GCPs).**
   Each GCP is recorded in absolute coordinates (e.g., UTM). See main text of this paper for discussion about choosing the number and distribution of GCPs for each trench wall. GCPs must be visible in a minimum of two photos with a clearly defined center point. We put a + on the nail heads with permanent marker to identify the center point. To record GCP coordinates, we set the total station in the UTM coordinate system and record the center point of every nail head. The location data for GCPs will need to be processed and saved in a format suitable for importing to PhotoScan (e.g., CSV file with PointID, East, North, Elevation). Rather than using GCPs with absolute coordinates, one could record GCPs in relative trench coordinates or measure the distance between pairs of nail heads and set scales in the model.

5. **Photograph the trench walls.**
   A comprehensive set of photographs is the most important factor for a successful IBM model and photomosaic. Take many photographs: image acquisition is fast, storage is cheap, and lacking coverage will ruin a model. Image acquisition guidelines can be found on Agisoft's website: http://www.agisoft.com/support/tips-tricks/ (last accessed July 2015).

The acquisition strategy in terms of time of day, number of photos, camera used, and shooting locations will vary depending on the trench setting and geometry. Photograph acquisition strategy, including camera and lens used, should be customized for each project and planned beforehand.

We use a GPS-enabled camera (optional) with 14 megapixel resolution, aiming for 60% photo overlap, both horizontally and vertically. Photos are captured orthogonal to the walls, kneeling and raising arms (or using an extendable pole) to acquire images, rather than tilting the camera up or down. Incorporating a few photographs taken at oblique angles can reduce systematic error (James and Robson, 2014). We acquire photographs beyond the area of interest, requiring more photos near the bottom of the trench, where shooting distance is smaller. We also photograph from the ground surface to capture detail in the opposite upper wall. We photograph the trench walls just after sunrise but before direct sun hits the trench walls, so there is ample ambient light and minimal shadows. Image acquisition took approximately two hours for both walls of a 32-m-long, benched trench and resulted in ~1300 photos.

Agisoft PhotoScan Professional Workflow

Processing times below are for a project with 689 JPEG photos taken with a 14 megapixel, GPS-enabled camera, processed on a laptop computer with 16 GB RAM and 2.70 GHz processor in PhotoScan v.1.0. This workflow complies with settings and terminology of PhotoScan v.1.1. Computer memory requirements and recommended configurations can be found on Agisoft's website at http://www.agisoft.com/support/tips-tricks/ and http://www.agisoft.com/downloads/system-requirements (last accessed July 2015). Italics indicate PhotoScan menu and processing options.

1. **Load images and remove any that are out of focus** (~5−30 min. for user).

2. **Align Photos** (~5 hr of computer processing).
   - This step aligns the images and outputs a sparse point cloud (tie points) and camera orientation, location, and distortion parameters.
   - Select *High* for accuracy.
   - Select *Generic* for pair preselection for non-GPS photos. Select *Reference* for pair preselection for GPS photos.
   - Note: in PhotoScan v.1.1, *Tie Point Limit* in the advanced options limits the size of the sparse point cloud. If foregoing the dense point cloud, we suggest raising the tie point limit above the default value of 1000; however, we have not tested the effect of different tie point limits on processing time or point cloud accuracy.

3. **Edit the Sparse Point Cloud** (~10 min for user).
   - This step removes high error and points outside the area of interest (e.g., trees in the distance).
   - Use *Gradual Selection* to remove points with high *Reprojection Error and Reconstruction Uncertainty*.
   - Manually delete misplaced, erroneous, and unnecessary points (e.g., points beyond the trench exposure).

4. **Add Ground Control Points** (~2 hr for user, depending on number of GCPs used).
   - This step scales and/or georeferences the model with a linear transformation in either a relative or absolute coordinate system.
   - Load relative or absolute GCP coordinates and names from file (or enter manually).
   - Manually place a marker for each GCP on two photos.

- PhotoScan automatically places the marker on all other photos where it is visible.
- Review automatic marker placement, and adjust markers as necessary.
- If using GPS-tagged photos, it's best to add GCPs in an absolute coordinate system.
- In the Settings dialog of the Ground Control pane menu, select the appropriate coordinate system (e.g., UTM Zone 12N) and change *Marker Accuracy* to the instrument precision limit (e.g., 1 cm) or other appropriate value.

5. **Optimize Point Cloud** (~10 min computer processing).
   - This step improves image alignment and reduces warping with a nonlinear transformation based on input control points and camera parameters.
   - In the Ground Control pane, uncheck all photos and check all control points. Note: unchecking control points with high error may increase accuracy of the optimization and point cloud.
   - Optimize photo alignment by clicking the magic wand button in the Ground Control pane menu.
   - Uncheck tangential distortion coefficients (p1 and p2) for optimization. These are usually small and can be ignored for most paleoseismic applications.
   - Delete any erroneous points that were created during optimization.
   - This step can be iterated with varying control points to minimize error.

6. **Build Dense Point Cloud (optional).**
   - This step builds a dense point cloud and will dramatically increase processing time.
   - It is usually not necessary for making photomosaic basemaps for logging but is critical for making high resolution topographic data.
   - Choose from five quality/density levels, depending on computing power and project needs.

7. **Build Mesh** (<1 min computer processing; maybe longer if use dense point cloud).
   - This step creates a triangulated irregular network surface from the point cloud.
   - Select *Height Field* for surface type, *Sparse Cloud* for source data, and *High* for polygon count.
   - Note: if reconstructing an entire trench rather than one wall, choose *Arbitrary* for surface type, but processing time will increase.
   - Interpolation can be *disabled* for more accurate results or *enabled* to fill holes.

8. **Build Texture** (~10 min computer processing).
   - This step adds low resolution texture (color) from the original photos to the model mesh.
   - Select *Generic* for mapping mode, *Mosaic* for blending mode, and *Disable* color correction.
   - Optional: clean up the model by deleting everything outside the target area.
   - Note: In PhotoScan, texture on the model displays at undesirably low resolution. Photomosaic resolution is set during export (see next step).

9. **Export Photomosaic** (~30 min computer processing at 0.5 mm resolution).
   - This step exports the photomosaic as an orthophoto.
   - We use a script written by Agisoft (see Python Script for Exporting Photomosaics in the electronic supplement) that facilitates exporting the photomosaic in a vertical plane with a look direction orthogonal to the trench wall. The native export menu can be used if precise control of look angle is not required.
   - If using the custom export menu enabled by the script, set appropriate *resolution* (< 1 mm) and *azimuth* (90° from field measurement; see step 1 in the Field Workflow section). Select *Mosaic* for blending mode. The script rotates the model counter-clockwise around the vertical Z axis. Choose image type by adding the desired extension to the file name (e.g., .png).

Geographic Information System (GIS) Workflow

This workflow describes the process we use to add a grid to the photomosaic and print sections in a suitable size and scale for mapping the trench walls. This process can be done in a number of other ways with a variety of programs. An advantage of doing it in a GIS (see Data and Resources) is that geologic data can be added, edited, and managed efficiently. See Figure S2 in the electronic supplement for an example log produced following this workflow.

1. **Set up a new GIS project with a UTM projection.**

2. **Load photomosaic exported from PhotoScan.**
   - Note: We have had trouble with large TIFFs in GIS, so we use a PNG image.

3. **Use the Georeferencing tool to rectify photomosaic image.**
   - Use the local trench coordinates of nail heads as georeference points.
   - For example, 19H 5V becomes 19, 5 when converted to *xy* coordinates for georeferencing.

4. **Choose a transformation.**
   - We use the second- or third-order polynomial transformation.
   - Note: In our experience, using the “adjust” transformation corrupts the image file.

5. **Turn on a map grid with 1 m spacing.**
   - Access grid options in Data Frame properties.
   - Note: Grid intersections may not align exactly with nail heads because nails are often slightly more or less than 1 m apart due to 3D irregularities of the trench walls.

6. **Export images of appropriately sized and scaled sections of the trench.**
   - The required scale depends on offset magnitude and grain size of material in the trench.
   - We export 3 m-wide sections vertically-oriented on 11 in. × 17 in. paper, but other trenches may necessitate different scales.