Mapping a Castle

How efficient and accurate is it to map a complex architectural structure using photogrammetric point cloud generation? How would the results of mapping such a structure compare to LiDAR scans? Pix4D, an image-processing software company, assembled a team to address these questions. The team made a comprehensive 3D reconstruction of a castle using image-processing software, and then compared the accuracy of the result to that of LiDAR.

The Chillon Castle of Switzerland is an island castle, surrounded by the waters of Lake Geneva on all sides, with a moat connecting it to land. The castle has a history of more than 1,000 years and has inspired many a poet, author and painter in its time, not to mention many of the 300,000 visitors that come annually to visit. Creating a large-scale 3D model of the historical site required a balance of accuracy, budget, time and resources. The entire complex consists of 25 buildings and three courtyards, with two surrounding circular walls.

The team chose to reconstruct the entire castle with images, while at the same time scanning several parts of the castle with LiDAR. LiDAR scanning of the entire structure was not feasible for the project: half of the castle is surrounded by water, making ground-based LiDAR impractical; the number of
viewpoints needed due to self-occlusions and small corners would render the project impractical in regard to time; and for nadir scans, aerial LiDAR would be necessary, making the scanning cost inhibitive. The LiDAR scans of the land-based facades served as a reference and later were compared to the measurements taken of the same facades from the photogrammetric point cloud, by calculating the margin of error.

Photogrammetric Method
For the entire project, 6,200 images were acquired in one day using six different cameras: a DJI Phantom 2 Vision camera, GoPro Hero 3+, Canon 6D, Sony Alpha7r, Sony NEX-7 and Canon7D. A reconstruction like this can be done with just one camera, but the project used several to provide a more reliable and accurate comparison to LiDAR. Nine people, the team members, were involved in image acquisition.

GCPs were used to ensure proper geo-referencing and were measured with a Total Station and GPS receiver from the land side of the castle. For points not accessible with the total station, a GNSS receiver was used in RTK-mode with a virtual reference station to measure 11 marked points in two different satellite constellations.

Using the image-processing software Pix4Dmapper, initial processing of the images was done by automatically using the image EXIF geotags (the initial GPS recorded location of the images). Feature points were extracted from the content of each individual image and then matched among all images. By using the GCPs, these triangulated matched points (the photogrammetric point cloud) were accurately georeferenced for a comparison with the LiDAR points.

The laser scan point cloud was registered from three individual laser scans (blue points: laser scan targets, red points: tachymetric points).

Figure 3: Color coded differences between the laser scan points and the photogrammetric triangulated meshes according to camera. Red and Blue values indicate missing data for the photogrammetric point cloud.
**LiDAR Method**

Two scanners were used for the laser scanning: the Faro Focus 3D X330 and the Trimble TX5 (identical to Faro Focus 3D X130). Three scan locations were set up independently to measure the land side façade of the castle, with ranging errors for both scanners specified with ±2 mm at 10 and 25 meters. Six spherical laser scan targets were placed around the scene.

The LiDAR point cloud had to be of the same coordinate system as the photogrammetric point cloud, so that they could be compared. In order to do this, nine distinctive points from the tachymetric measurement were used, along with the laser scan targets, during registration of the scans.

This resulted in the mean residuals of 2 mm for the laser targets and 10 mm for the tachymetric points after adjustment, which seemed good enough to use, considering the fact that the tachymetric points were not perfectly detectable in the gridded point cloud.

**Comparison**

The final photogrammetric point cloud results were compared to the laser scan point clouds using the open-source software CloudCompare. Figure 3 shows the distance to the reference data (laser scan) for each photogrammetric point cloud. Since photogrammetry and LiDAR sample the underlying surfaces differently, simply calculating the distance to the closest corresponding point in each point cloud generally does not yield an accurate estimate of the distance between the surfaces.

Therefore, the differences between the photogrammetric and LiDAR point clouds were obtained by first triangulating the photogrammetric point clouds (or creating a mesh surface) and then calculating the surface-point distance for every point of the laser scan cloud. Figure 3 shows the color-coded difference between the laser scan and the reconstructions of the different datasets as signed distances in the range [-150 mm, 150 mm]. In the histograms, the distance for most points fall within this range.

The red areas in some of the plots do not represent reconstruction errors, but simply show that no data has been acquired in this area for the dataset in question.

For all datasets, a Gaussian distribution was fitted to the deviation histograms and the mean and standard deviation were estimated. Table 1 summarizes these results.

**Conclusion**

After the projects were processed and analyzed, the image-derived 3D model’s results were found to be generally comparable to the results of the laser scanner. For a model that is satisfied with ±5 centimeter accuracy, photogrammetric mapping can be a very feasible and efficient alternative to LiDAR scanning.

Several main factors that influenced the accuracy of the photogrammetric method included:

- Using fisheye cameras with a 180 degree field of view. Smaller angle fisheye lenses on good cameras had results comparable to other perspective lenses.
- Using rolling shutter cameras, which increased projection and xyz errors. While the projection error of the global shutter cameras is around 0.5, the rolling shutter cameras have an error of 2 or 3 pixels. Taking the rolling shutter into account in the mathematical model would most likely decrease this error.
- Whether the camera was mounted to a tripod or not. Datasets taken with a tripod have the lowest deviations.

In addition to the comparable accuracy to LiDAR, the photogrammetric data was easy to acquire and use, had a reasonable cost, and had a highly reduced acquisition time.

**Table 1**

Comparison of the different datasets to the laser scan data. The deviation to laser corresponds to a Gaussian fit of the deviation histograms in Figure 3.

<table>
<thead>
<tr>
<th>Lens Type</th>
<th>Camera/Lens</th>
<th>Acquisition</th>
<th>Acquisition Time</th>
<th>Deviation to Laser (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perspective</td>
<td>Sony NEX-7 16mm</td>
<td>Tripod</td>
<td>20 minutes</td>
<td>-0.2 +/-4.5</td>
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<tr>
<td>Perspective</td>
<td>Canon 7D 20mm</td>
<td>Tripod</td>
<td>20 minutes</td>
<td>-0.4 +/-4.2</td>
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<tr>
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<td>Sony Alpha-7R 16mm</td>
<td>Tripod</td>
<td>20 minutes</td>
<td>-0.4 +/-4.4</td>
</tr>
<tr>
<td>Fisheye</td>
<td>Phantom Vision 2 UAV</td>
<td></td>
<td>15 minutes</td>
<td>-0.7 +/-6.3</td>
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<tr>
<td>Fisheye</td>
<td>GoPro Hero3+ Handheld</td>
<td></td>
<td>10 minutes</td>
<td>-1.3 +/-7.1</td>
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<tr>
<td>Fisheye</td>
<td>Canon 6D 8mm</td>
<td>Tripod</td>
<td>20 minutes</td>
<td>-2.8 +/-6.0</td>
</tr>
</tbody>
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Dr. Christoph Strecha is the CEO and founder of Pix4D, a Swiss company which develops and markets software for production of survey grade 3D models and orthomosaics from UAV, aerial and terrestrial images.

Krista Montgomery has a background in journalism and currently works with Pix4D as a writer and content producer.