Survey of Ely Bridge, Monticello, Iowa

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Project purpose

The purpose of this project was to assess the feasibility to restore the Ely Bridge in Monticello, Iowa, a structure listed in the National Register of Historic Places. The author was invited by the Department of Civil Engineering of the University of Colorado, Denver, to create a three-dimensional scaled wire frame of the bridge to be used in a finite-element stress analysis. This report describes the effort of creating this digital three-dimensional wire frame, using photogrammetric tools. This purpose does not create the need for a highly precise result for photogrammetry. It is estimated that this type of project only requires an overall accuracy of about ±4 inches in terms of the position of details.

Specific Difficulties

There were substantial difficulties in the collection of suitable images, which included:

- The bridge is surrounded by thick vegetation in the form of tall grasses, wide and leafy trees, and inaccessible terrain. The timing was the early fall when vegetation was at its lushest. No ground features were available for pass points or control.
- The day was very windy, and there was no opportunity to choose the date. It was too windy for drones, camera poles, or the use of vegetation features as pass points (too much motion).
- The limited availability of shot angles prevented the collection of sufficient images for automated surface extraction.
- The irregular surface of old bridges causes surface detail to look significantly different from different view angles, making the automated or manual selection of pass points difficult.
- Due to the local interest in this work, there was a significant number of people milling around, making the selection of suitable perspectives difficult.

Project Method

The creation of the wire frame of the bridge was done in various steps, as follows:

1. Camera calibration
2. Ground control placement, survey, and calculations
3. Image collection (photography)
4. Photogrammetric block adjustment
5. Feature digitization
6. Digitized detail export to CAD

Camera calibration

The camera that was used for the taking of the images is the inexpensive Sony αNex-5 Alpha, with a nominal focal length of 16mm, and a 14-megapixel sensor. This camera was hand-held, and high exposure speeds were used (1/600th of a second).

Capturing large objects within the vary small space of a lightweight commercial camera would be difficult unless one has a precise idea what the error household of the internal camera space is, including the distortions that an inexpensive camera lens introduces at the image plane. These distortions, and the actual focal length, were calculated to the micron. This was achieved with a "camera calibration". This camera calibration has been completed for the Sony camera mentioned above. This was done prior to the trip to Monticello, using the commercial PhotoModeler software. This allowed image collection to begin while operating within a known amount of image distortions.

The resulting calibration results exceed project purpose needs, which facilitates data processing. The results are: Focal length = 16.342648 mm ± 0.994 mm; largest residual = 1.327 pixels, automated point RMSE = 0.314 pixels, and the following image distortion values:

K1 - radial distortion 1, value : 2.123e-004, deviation : K1: 3.5e-006
K2 - radial distortion 2, value : -1.392e-006, deviation : K2: 1.0e-008
K3 - radial distortion 3, value : 0.000e+000
P1 - decentering distortion 1, value: 1.186e-004, deviation : P1: 6.9e-006
P2 - decentering distortion 2, value: 0.000e+000

Ground control placement, survey, and calculations

Utilizing special targets developed for the purposes of marking points surveyed on the ground, the photogrammetric block acquired a ground reference (local coordinate system). This was used to scale the data that are extracted from the images. Figure 1 shows one such target (target "D") that is placed over a mark on the pavement of the bridge. This mark was surveyed with the help of a total survey station. In Figure 1 one can also see a small white "x" that resulted when this position was digitized in the images.

Figure 1: Target

Note that the control field was three-dimensional, in the sense that it started to be collected on the surface of the bridge, then dropping points down to both sides, and finally wrapping the trigonometric survey underneath the bridge. Thus, the whole of the bridge was surrounded with a control field from all sides that were accessible.

Image collection

The photography of the bridge was carefully and strategically done so that the control points and all necessary bridge detail appeared in two or more images. A total of 35 images was collected with a hand-held camera (14 Mpixel).

Photogrammetric block adjustment

The photogrammetric block adjustment (bringing all images into the same space and into the ground control reference) was completed using 644 manually digitized pass points and five ground control points, with end results as follows:

- An overall RMSE of 0.88 pixels, and
- A largest error of 1.94 pixels

These error levels are considered acceptable for the purpose, both in general terms and in terms of project requirements. Depending on camera-object distances, the image pixel size on the ground, or ground sample distance (GSD), varied between 5 mm (for close-up shots) and 2 cm (for the longest shots). Given that rock surfaces look very different from different view angles, the achieved overall 0.88 pixel RMSE is very good.

Feature digitization

Of the 35 pictures that were taken, a selected 20 were used to digitize the bridge from various angles. In Figure 2, one can see the dashed line that represents the concrete slab.

Figure 2 – One of the images used for scaling, leveling and digitization

The estimated positional accuracy of the bridge details is ±5 cm.

In Figure 3, some of the digitized detail is also shown. Note that some of the larger irregularities of the bridge stone were also captured.

Figure 3 - One of the images used for digitizing the arches and other detail

Exporting digitized detail to CAD

The following is a collection of four views that was extracted from the resulting CAD file.

This mapping project had one purpose in mind, and that was the creation of a scaled model of the bridge to be used in stress analyses. Such a model was created photogrammetrically and exported to AutoCAD.

It must be stressed that some detail was not visible. For example, both embankments concealed the actual shape of the footings, and so simple straight lines represent these areas, see (Detail 1) and (Detail 2) in Figure 4.

The digitized shapes reflect the irregularity of the rock used for the bridge.

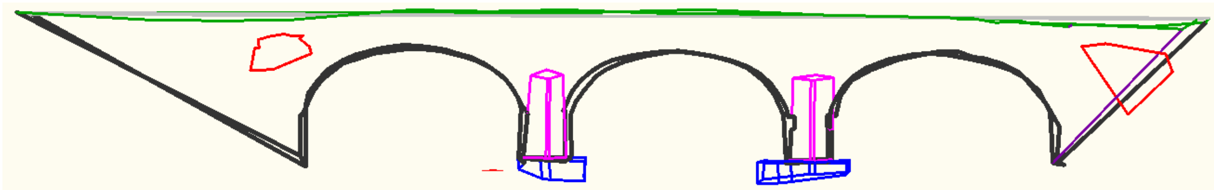

Figure 4 - View from the West (South is to the right)

General comments

The lack of data underneath both ends of the bridge prevented the preparation of a complete bridge model. However, the data presented above were sufficient to prepare a finite element model of the bridge for the purposes of structural analysis. This included assumptions on how the bridge supports are structured under the ends.

This wire frame was successfully utilized in the creation of a complete, three-dimensional finite element stress model of the bridge.