Conference Paper

Automatic deformation measurement with a digital still video camera

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Abstract:
This paper shows the application of a digital still video camera to the measurement of deformations occurring during the dehydration process of concrete parts over several months. A block of 28 images, arranged in two convergent stripes, was recorded with a Kodak DCS200 in six epochs. Using signalized points and a set of coded targets, the dataflow in repeated measurements could be widely automated. The camera was calibrated for each epoch individually by photogrammetric self-calibration techniques.

An externally verified precision of the deformation vectors of 3/3/6 micron in X/Y/Z coordinate direction was achieved over an object space with a largest dimension of 80 cm, proving the high accuracy potential of a digital still video camera applied to relative 3-D measurements.

Keywords: still video camera, automatic data flow, relative accuracy

1 Introduction
The measurement of objects such as deforming parts has often been realized using methods such as interferometry, Moiré techniques, theodolite measurement systems or coordinate measurement machines. But various disadvantages (high prices, system has to rest stable during the whole campaign, measuring effort, influence of touching the object) lead to the demand of new techniques.

Due to the improvement of sensors and equipment, high resolution digital still video cameras have found wide interest among photogrammetrists during the past few years. Compared with those techniques mentioned above, there are some obvious reasons which make the use of digital photogrammetry more than just a useful alternative: As the equipment may be removed between the epochs, it can be used for other projects. The non-contact method and the short time it takes to get the images reduce the mechanical and climatical influence on the object.

The use of coded targets [Van den Heuvel, Kroon, 1992] [Knobloch, Rosenthal, 1992] [Schneider, Sinnreich, 1992] [Wiley, Wong, 1992] [Höflinger, Brandstätter, 1995] [Homainejad, Shortis, 1995] [Niederöst, 1996] leads towards the automation of the measurements, especially as far as repetitions using the same network configuration are concerned.
Task of this project was to monitor the deformation of three concrete parts (Fig. 1) over a duration of approximately five months. Using digital photogrammetry, we were able to achieve a sufficient relative accuracy. In addition, the evaluation of the measurements could be widely automated.

Fig. 1: Concrete parts with iron bars

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Used Camera: Kodak DCS 200

The Kodak DCS200 came onto the market in 1992 as the first high resolution still video camera. The mirror reflex part is a modified Nikon 8008s camera with a 1524 x 1012 pixel CCD sensor, each pixel with a size of 9 µm. There are two versions offered either with a black and white or a one-chip color sensor. Image storage is done using a 2 MB DRAM or a 80 MB internal harddisk which allows to store 50 uncompressed images. For our studies we used the DCS200 with color sensor, internal 80 MB harddisk and a Nikkor 28 mm lens. The digital images are transferred from the internal camera harddisk into a host computer via SCSI interface. The images can then be converted into different standard image formats e.g. using a module in Adobe Photoshop.

Photogrammetrists have been using high resolution digital still video cameras in a large number of applications since 1993 e.g. [Peipe et al., 1993] [Fraser, Shortis, 1994] [Maas, Kersten, 1994]. A general problem with the DCS200 and similar cameras has been the instability of the interior orientation, which leads to a severe degradation of the accuracy potential in absolute 3-D coordinate measurement tasks [Maas, Niederöst, 1997].

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Arrangement and procedure of measurements

Cast concrete was poured onto existing parts causing deformations due to the different moisture. Task of the project was to monitor the deformation of the concrete parts over several months. The dimensions of the three parts (with different cast concrete added) were 1.6 m x 0.2 m x 0.1 m. On the concrete parts, a conventional target was attached every 25 mm. Those points would later be used as deformation points. For reasons of symmetry, only one half of the pieces had to be monitored.
Besides the three concrete parts, two iron bars were fixed to the ground with screws. On those bars, conventional targets were attached in 75 mm intervals to serve as control points. In addition, coded targets were added close to the conventional ones. Besides the use for approximative orientation of the images, they would be used as check points in the final adjustment over all epochs. Fig. 3 shows a section of the object with the three types of targets.

![Fig. 3: Deformation-, control- and checkpoints](image)

In order to simplify the evaluation, the photogrammetric configuration was kept as similar as possible over the 6 six epochs. The objective was to take the same number of images from about the same camera positions. Therefore two convergent stripes of 14 pictures per stripe were taken with an average image scale of 1:20.

The temporal sequence had to be adapted to the dehydration process. Over a duration of five months, six epochs were measured with progressive intervals. The first interval was only one week, whereas the last break between two epochs lasted three months.

4 Coded targets

The automatic data flow is realized using a set of coded targets [NIEDERÖST, MAAS, 1997]. The following features had to be considered when developing the coded targets and the appropriate software:

- No necessity to use retroreflecting material
- Independence of position in image
- Independence of target’s scale (considering a certain minimum target size)
- Independence of rotation of the code
- Independence of affine transformation
- Detection of occlusions possible

In order to get the (pixel-) coordinates and numbers of all coded targets in one image, the following steps are necessary:

- Detection using centre of gravity:
  Any bright object of a certain size is detected as a likely part of a coded target.
- Distinction of targets and other image objects:
  Using concentricity and size relations, the coded targets are separated from other bright objects.

![Fig. 4: Coded targets with circular code](image)
• Least squares matching:
  - Pixel coordinates of target
  - Parameters of affine deformation:
    The affine deformation is reduced to a 5 parameter solution (2 translations, 2 scales, 1 shear) which eliminates the high correlation between the two shear parameters.

• Sampling of grey values on the projected code circles

• Determination of target number:
  - Detection of starting angle
  - Reading of code including calculation of bit values: Using the grey values in each sector, the value of each bit is determined und thus the code is read.
  - Decoding: The appropriate number is now calculated using a simple formula [Nieder-Öst, 1996].

• Check of decoded number:
  Several tests are performed to avoid type 1 and - more important - type 2 errors.

The advantage of this system is the fact that occlusions can be detected, helping to keep the percentage of wrong numbers low. The coded targets have been tested using various data sets and turned out to be a useful means with regard to the automation of repetitive measurements. While type 1 errors occasionally were detected especially with rather small targets, a type 2 error did never occur.

5 Widely automatic data flow

The use of coded targets is a great benefit in repeated measurements.

In the first epoch, the advantage of working with coded targets does not yet give it’s full competitive edge as no approximative object coordinates of the conventional targets are available.

Each conventional target has to be measured interactively in at least two images. In addition, the coded targets are measured in every image automatically. This allows to calculate a approximative solution for all object coordinates and to measure them automatically using back projection of the object coordinates into the remaining images. As soon as all pixel coordinates are known, the definitive solution for the first epoch can be computed.

Henceforward the procedure is fully automatic in principle (Fig. 5). The measured coordinates of the coded targets allow for the computation of a approximate orientation for each image. Using the object coordinates of the previous epoch, the conventional targets can now be located and

Fig. 5: Automatic data flow
measured automatically (least squares matching), assuming that the deformations are smaller than the target diameter. In a second adjustment, the definitive solution for the separate epoch is calculated.

The shown data flow is automatical in principle. User interaction is only necessary to give the input data and to start the several programs.

6 Results and Conclusion

In the end of the campaign, all six epochs were combined in a final adjustment to get a consistent solution over all sets of data. Therefore the control points (conventional targets on iron bars) were held fix over all epochs. Using those control points, the coordinates of the deformation points (conventional targets on concrete parts) and of the check points (coded targets on iron bars) were computed. The camera was calibrated simultaneously, introducing one independent additional parameter set for each epoch.

As a result we get the deformation vectors between the single epochs (Fig. 6).

The main effects due to the changing moisture in the concrete bars can be represented graphically. The altering x-coordinates especially in the third bar show some fissures. Changes of the y-coordinate indicate a slight canting of the bars. The z-vectors indicate that due to the changing moisture of the new material the endzones of the concrete parts are bending upwards. The different behaviour of the three bars concerning fissures and bending can easily be seen.
In order to verify the achieved results, the exterior accuracy was calculated using the coded targets as check points with zero deformation.

<table>
<thead>
<tr>
<th>Interior accuracy (bundle adjustment)</th>
<th>Exterior accuracy (check points)</th>
</tr>
</thead>
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<tr>
<td>$\hat{\sigma}_0$ [µm]</td>
<td>$\hat{\sigma}_X$ [mm]</td>
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<tr>
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<td>$\hat{\sigma}_Z$ [mm]</td>
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<tr>
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<td>0.0031</td>
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<tr>
<td>0.0032</td>
<td>0.0062</td>
</tr>
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</table>

Tabla 1: Results of deformation measurements

These relative measurements show very high accuracy and good consistency between internal and external accuracy parameters. Unlike absolute 3-D measurements, relative measurements of small displacements aren’t affected by the stability problems of the camera. The fact that in depth direction (Z) the external accuracy is better than the internal figure can be explained by correlations between coordinates caused by the introduction of self-calibration parameters. Related to the length of the observation area of ~80 cm, the achieved accuracy corresponds to a relative accuracy of better than 1 : 250'000. With this accuracy potential, relatively low instrumental effort and the possibility of fully automatic data processing, digital photogrammetry turns out to be a valuable alternative to other existing measurement techniques.

References:

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