# PHOTOGRAMMETRIC SYSTEM CALIBRATION


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## ABSTRACT

System calibration means a process where the main purpose is to establish the overall accuracy of survey results. It is also important to analyse those factors which are critical for the accuracy. System calibration integrates instrument calibration and testing of survey methods, programs and personnel in one process. A photogrammetric survey for mapping or for digital terrain model is a complex process, where the human factor, the stereo-operator, is in key position. Also the properties of ground objects are quite often such that there are problems to identify and to locate them. Photogrammetric system calibration makes it possible to handle these kinds of problems, which are beyond easy control under operational conditions. This report describes the experiences of photogrammetric system calibration obtained in Tampere University of Technology, Finland. The reference used is the calibrated stereomodel of Rusko, which is an accurately surveyed test field for large-scale photogrammetric mapping. It gives us the means to establish the accuracy of photogrammetrically mapped coordinates in various point classes, to evaluate the capabilities of stereo-operators and to train them. It has also been possible to find out the critical parts of the photogrammetric survey process. They are the resolving power of the photography, the image deformations due to heat in the stereoplotter, the stereo-operator's skills, and the characteristics of ground objects. Accordingly, the training of stereo-operators seems to be an important way to improve mapping accuracy. Other important things are improvement of the resolving power of the camera/film combination, image motion compensation, the careful handling of photographs throughout the process, and the control of image deformations in the stereoplotter. In the future use of digital images will improve the survey process, for example, in respect of image deformations.


## INTRODUCTION

The design of civil engineering projects requires data about the terrain surface in the form of plans, maps, and digital elevation and terrain models. As planning methods are getting more sophisticated and accurate than ever before, this sets new requirements for the survey data. Especially geometric accuracy must be higher than before. Today most of this survey data is generated by photogrammetric methods. Modern cameras are accurate instruments, as are analytical and digital stereoplotters, too. Their accuracy can be tested by instrument calibration. But they are only part of the photogrammetric survey process. The rest involves for example the execution of the flight missions, the photographic properties and deformations of the films, the personal capabilities of the stereo-operators, the accuracy of the control points, and the properties and interpretability of terrain details. In many cases the accuracy of stereophotogrammetry in mapping applications has been overestimated. One can see several reasons for this. First, the accuracy figures are mainly related to targeted or otherwise well-defined points. Second, the personal capabilities of the stereo-operators have not been considered properly. And third, the difficulties to identify and to locate terrain points and other features have not been taken into account. These are matters which cannot be handled with instrument calibration and theoretical considerations only. Here we propose a concept and methods of system calibration to establish the accuracy of the final mapping products, and to analyse those factors which are critical for the accuracy.

## PHOTOGRAMMETRIC SYSTEM CALIBRATION

### Definition

Traditionally calibration is understood as instrument calibration which establishes the accuracy of the surveying instruments. That is necessary but not enough for complicated survey processes. What is needed is system calibration. It means a process where the purpose is to establish the overall accuracy of the survey results. It integrates instrument calibration and testing of survey programs, methods and personnel in one process which follows the steps of the real survey process. This is a very demanding task, especially when one wishes to analyse the results thoroughly. In fact it is not always possible to find out all the reasons and connections which have an effect on the accuracy from the results of system calibration alone. In this respect the conventional methods of instrument calibration are important, too. The above definition involves more than the well-known photogrammetric test field calibration. In any case, when system calibration is applied to the photogrammetric mapping process, there has to be an accurately measured test field, but there also have to be various point classes so that there are targeted points, points on various terrain surfaces, and details of man-made features. The need for this kind of mapping test field became obvious during experimental work in Kaukajärvi area, Tampere, Finland (Niskanen, 1990, and Salmenperä, 1990).

**Calibrated stereomodel of Rusko**

There exists a photogrammetric test field for the purposes of system calibration in the Rusko area, Tampere, Finland, near Tampere University of Technology (Rantaniemi, 1993, and Salmenperä, 1993). It has been measured and photographed in 1992. There are 61 control points with a standard deviations of 2 mm and approximately 1600 test points with a standard deviation of 5 mm for the coordinates and the heights. The test points are located on terrain surfaces or on man-made features. The area has been photographed with Wild RC20 (c = 153.19 mm) on Kodak MS2448 and Agfa AvChr 200 films. The flying height is 500 m, which gives the scale 1:3300. This scale is usually converted to a mapping scale of 1:500 in urban areas in Finland. Forward motion compensation has also been used, which is necessary to produce high-quality images for large-scale mapping. The images are available in digital form, too. As the test field exists as these images, it is called the calibrated stereomodel of Rusko.

The images form two stereomodels. One of them is used for research and system calibration and it has approximately 1200 points. The other one is used for training purposes and it has 400 test points. The resolving power of the camera/film combinations varies from 25 to 30 lines/mm as evaluated from test figures. The geometric accuracy of the stereomodels has been tested by bundle block adjustment, where the image coordinates of all the targeted control points are adjusted with known ground coordinates. The resulting standard deviation of the unit weight equals 4.5 μm, which corresponds to 15 mm on the ground.

## TEST RESULTS

**Testing of stereo-operators**

The stereo-operator has to identify, classify and select points which belong to model surfaces, lines and objects, and then he or she has to point at them. Operators seem to have their personal ways of doing this, which results in systematic errors. Especially heights and unsymmetric objects show these kinds of systematic errors. The calibrated stereomodel can be used to test their capabilities to perform these tasks and to classify them.

The operator starts the test by internal and external orientation of the stereopair. Then he or she goes over to computer-controll so that the measuring program brings the measuring marks near the test points. In height measurement, the operator has to set and record the height only, but when all the coordinates have to be measured, the given position is set randomly aside and the operator has to set the measuring marks in all dimensions. Before the end, part of the measurements are repeated. After one day's work the measurements are processed and the operator's performance is evaluated. In this stage long-term statistical means are used as reference (table 1).

**Identification of terrain points**

Good definition of the points to be measured is the basic condition for achieving high and uniform accuracy in a photogrammetric survey. To define a point in a satisfactory manner, ground objects or features must have symmetrical form, suitable size and sufficient contrast with the surrounding area (Blachut, Chrzanowski and Saastamoinen, 1979). Very few natural or man-made ground features meet these requirements. Relevant factors are also the scale of the photography, the resolving power of the camera/film combination and image motion compensation. Furthermore, colour photos usually give better interpretability than black-and-white photos, and details can be recognized more easily if they cast shadows. On the other hand shadows may cover details. And, to make the matter still more complicated, the definition of terrain points to be measured is a matter of subjective judgement with the stereo-operator.

Another side of this question is the role of quality control. According to Finnish instructions, photogrammetrically measured coordinates have to be checked against field surveyed coordinates, using a random sample (The Finnish Society of Photogrammetry and Remote Sensing, 1993). Because of identification problems, the instructions define the concept of the range of interpretability. If the deviations in the photogrammetrical coordinates from the field surveyed coordinates are less than the range of interpretability , the deviation is set to zero, or taken as errorless.

**Dimensional stability of photographs**

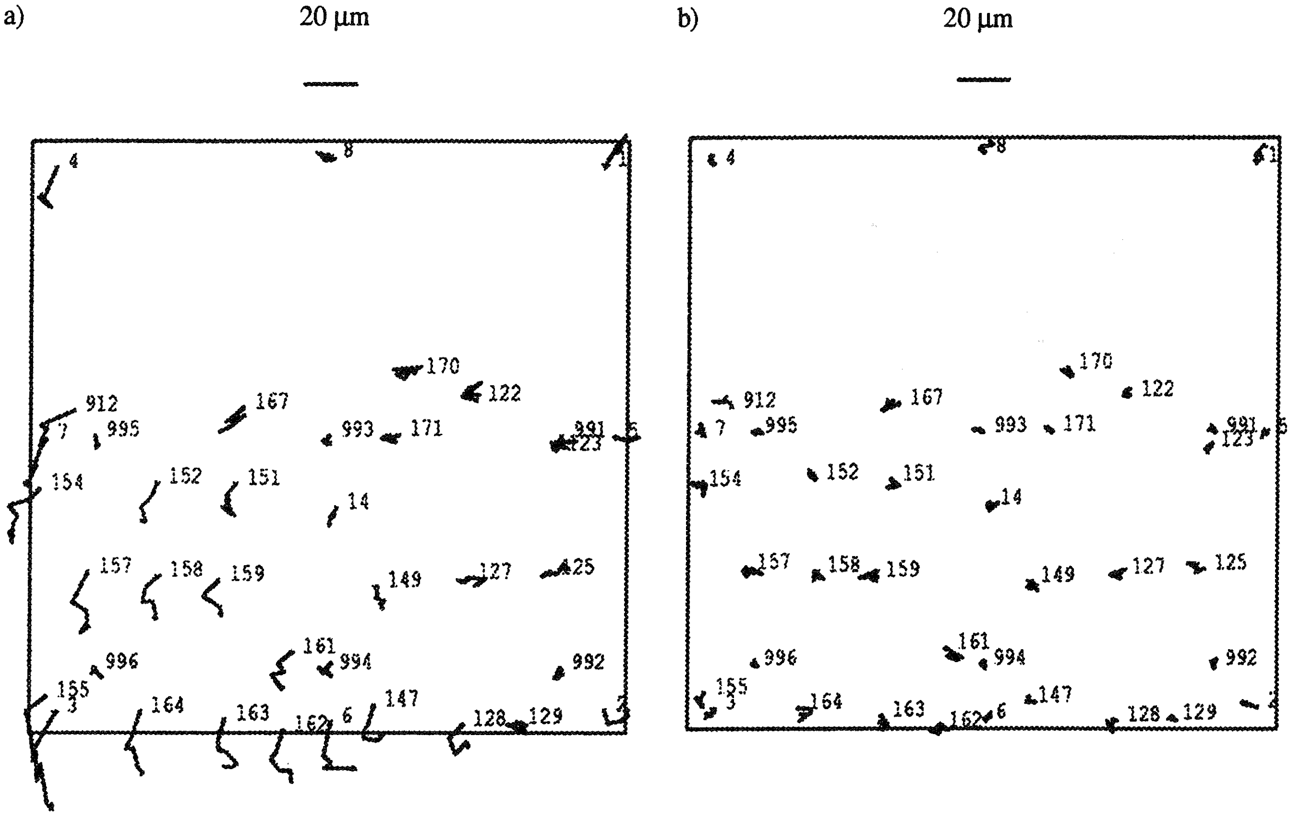
Uneven heating of the photographs can be a problem when using some analytical stereoplotters (Salmenperä and Miettinen, 1993). For example fluorescent tubes have high surface temperatures, they illuminate only part of the photographs and the area of intense heating moves as the work proceeds. This gives rise to local deformations. The way the photos are placed on the picture carriers below the cover glasses may strengthen these deformations. Then the pressure of the cover glass may at certain spots hinder the deformations. The resulting deformations are then both local and time-dependent and may exceed tens of micrometres (figure 1). In addition, the deformations at the locations of the fiducial marks are generally not representative of the deformations throughout the photograph. This means that corrections for film distortion cannot be computed reliably from the measurement of the fiducial marks unless special actions are taken. It is possible to reduce these deformations. One way to do this is to use a light source which is placed outside the plotter. Another means is to let the temperature of the photos reach the working temperature before the cover glasses are tightened. In addition, one could produce cover glasses which would be slightly lifted from the picture carriers, while still keeping the photographs flat. In the future the expanding use of digital images will improve the photogrammetric survey process in this respect.

Table 1. Calibrated stereomodel of Rusko, Tampere, Finland. Systematic errors and standard deviations in various point classes. Combined test results of six stereo-operators who represent good measuring practice. Shadow means object's own shadow.

| OBJECT | X-COORDINATE | | Y-COORDINATE | | HEIGHT | |
|---|---|---|---|---|---|---|
| | Systematic error [mm] | Standard deviation [mm] | Systematic error [mm] | Standard deviation [mm] | Systematic error [mm] | Standard deviation [mm] |
| Ditch | | | | | -113 | 60 |
| Lane centre line | | | | | -45 | 49 |
| Street centre line | | | | | -37 | 48 |
| Embankment | | | | | -40 | 44 |
| Top of curb (no shadow) | | | | | -40 | 43 |
| Paved yard | | | | | -22 | 52 |
| Sand road | | | | | -48 | 28 |
| Rock outcrop | | | | | -17 | 50 |
| Grass area | | | | | -35 | 34 |
| Other ground | | | | | -36 | 32 |
| Edge of pavement (no shadow, foot of curb) | | | | | -20 | 43 |
| Forest ground | | | | | -3 | 45 |
| Edge of pavement (with shadow, foot of curb) | | | | | -19 | 38 |
| Edge of pavement (no curb) | | | | | -23 | 32 |
| Ploughed land | | | | | -9 | 38 |
| Lawn | | | | | -20 | 32 |
| Top of curb (with shadow) | | | | | -12 | 31 |
| Gravel | | | | | 12 | 28 |
| Sand | | | | | 1 | 23 |
| **Targeted control point** | **1** | **11** | **-7** | **10** | **13** | **25** |
| Manhole | 12 | 22 | 1 | 17 | -5 | 33 |
| Well-defined roof structure | -4 | 26 | -8 | 21 | -12 | 45 |
| Curb line | -2 | 27 | -17 | 18 | -15 | 26 |
| Car electricity post | -22 | 18 | -20 | 19 | -58 | 70 |
| Electric distribution box | 19 | 26 | -12 | 24 | -9 | 37 |
| Painted street centre line | 22 | 20 | 8 | 29 | -30 | 47 |
| Railing | 28 | 31 | -5 | 24 | -17 | 55 |
| Post | -10 | 45 | -5 | 33 | -108 | 50 |
| Other roof structure | 1 | 46 | -16 | 36 | -30 | 78 |
| Fence post | 14 | 41 | 32 | 50 | -20 | 164 |
| Wall | 18 | 61 | -16 | 43 | -63 | 162 |
| Short post | 39 | 36 | 80 | 46 | -207 | 91 |
| Building foundation | -41 | 69 | -30 | 67 | -15 | 42 |

**Training of stereo-operators**

Training of stereo-operators seems to be an important way in which corrective measures can be taken to improve mapping accuracy. Modification of survey standards and instructions may give reasons to train experienced operators, too. One stereomodel of the Rusko area is reserved for training purposes. There are two possibilities to organize a training session. One way is like the stereo-operator's test, where the measuring program brings the measuring marks near the test points and the trainee sets and stores the coordinates and/or the height. Then the measurements are processed and analysed to find out possible problem areas and to establish the trainee's starting level. The other way is arranged so that immediately after the measurement the program shows the correct position and the trainee can then learn the correct way to point at the test points.




| Points: | | |
|---|---|---|
| | 1 - 8 | Fiducial marks |
| | 14 - 912 | Targeted control points |
| | 991 - 996 | Calibration grid points on picture-carrier plate |

Figure 1. Changes of the picture-carrier coordinates. a) A test where the measurements were started immediately after the system start-up. The light source was the stereoplotter's fluorescent tube. b) A test where special care was taken to reduce the variation of temperature. The light source was placed outside the stereoplotter.

## CONCLUSIONS

The experiences show that the photogrammetric system calibration, which corresponds to the photogrammetric survey process, can be used to establish the accuracy of the coordinates of the measured terrain points. It has also been possible to find out the critical parts of the process. They are the resolving power of the camera/film combination, the image deformations due to heat in the stereoplotter, the capabilities of the stereo-operators, and the characteristics and interpretability of the ground objects. Accordingly, corrective measures can be taken to improve the mapping accuracy. They are the training of stereo-operators, image motion compensation, the careful handling of photographs throughout the process, and the control of image deformations in the stereoplotter. The research on the photogrammetric system calibration has also influenced the instructions and recommendations on photogrammetric surveying in Finland (The Finnish Society of Photogrammetry and Remote Sensing, 1993 and 1995). In the future use of digital images will improve the survey process, for example, in respect of image deformations. As the calibrated stereomodel of Rusko is available in digital form, it can be used for the system calibration of applications of digital photogrammetry, too.

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