STANDARDS FOR LARGE-SCALE PHOTOGRAMMETRIC MAPPING

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ABSTRACT:

Standards for the photogrammetric production process have been established during the development of a new manual for the technical activities of the cadastral agency of The Netherlands. The paper gives an introduction to this manual which focusses on the quality assurance of mapping processes and products. A consistent set of standards and guidelines has been developed based on a systematic description of quality control. The manual is based on a comprehensive unified approach to large-scale photogrammetric mapping and serves as a basis for contracting out photogrammetric map production. As such this manual satisfies a widely felt need for standards for aerial photogrammetry and other mapping techniques.

1. INTRODUCTION

This paper deals with the quality assurance of the process of large-scale photogrammetric mapping and the resulting products. In the last few years this topic has been studied as part of the development of a new manual for the technical activities of the cadastral agency of The Netherlands (in Dutch: *Handleiding Technische Werkzaamheden* or HTW). It has been developed in close collaboration of the cadastral agency and Delft university.
The HTW has a long history starting in 1902 with the publication of the first version of the manual. As technical activities and processes are subject to rapid changes their standardization will have to be updated on a regular basis (Koen, 1995). It is obvious that the last version of the HTW, published in 1956, is outdated.
The new HTW has a much broader scope than cadastral surveying only. It can serve as a reference manual for large-scale mapping independently of the measurement technique applied. The manual contains background knowledge in the fields of adjustment and testing theory, geometric quality control and connection of point fields. Furthermore it contains chapters on control and field surveys (including GPS), map renovation and large-scale aerial photogrammetry (Cadastral agency of The Netherlands, 1996).

In the chapter on photogrammetry no distinction is made between analytical and digital photogrammetry as far as the photogrammetric process is concerned. Digital aerial photogrammetry however (still) requires the conversion of the photographs to digital images using a scanner. Guidelines for scanning are part of the manual.
Photogrammetric mapping and map revision are explicitely distinguished. The main reason is the introduction of the digital photogrammetric technique called mono-plotting that can be used for map revision.
Although height is dealt with in case of a three dimensional measurement technique such as photogrammetry, the HTW is basicaly restricted to mapping in two dimensions.

The purpose of the manual is to guarantee the geometric quality of cadastral products such as cadastral maps, cadastral field sheets and control points. For this purpose sets of guidelines have been developed for all data capture and data processing techniques, which are used by the cadastral agency. The guidelines are based on the required quality of the cadastral products.
A quality model has been developed to obtain a consistent set of specifications and to facilitate the description of geometric quality (Salzmann, 1996). This model is at the basis of the manual and underlies the description of the various techniques, which are treated within the framework of a common procedure of data capture and data processing. This paper focusses on the standards that have been developed for quality assurance of photogrammetric mapping.

2. LARGE-SCALE MAPPING IN THE NETHERLANDS

In The Netherlands most large-scale topographic surveys are linked, in one way or another, to the base map of The Netherlands, which currently covers about 80% of The Netherlands and will be completed by 1999 or 2000. The map scales used are 1:1000 (built-up areas) and 1:2000 (rural areas). The map is produced digitally and will be converted into an object-oriented map in the future. Height is not an element of the Dutch large-scale base map. The map is produced

under the responsibility of public-private partnerships. Participants are the national cadastral agency, the utilities and municipalities. The actual surveying and mapping is carried out by the participants or by private contractors.
The accuracy requirements are different for the various users of the map. The cadastral agency uses the base map for the renovation of the cadastral map. This is possible because topographic features often coincide with cadastral boundaries. Furthermore buildings can be copied from the base map, because the cadastral map has to depict the perimeter of buildings.
The utilities use the map as the basis for the mapping of (underground) pipes and cables. The location of pipes is usually described relative to buildings and other structures on the map. Most utilities require a high relative precision in a limited area of the map (most pipes are located under or near to roads). Therefore they do not necessarily need a map with a full coverage. The setting-out of pipes is generally not performed in map-coordinates, but using measures relative to buildings.
The municipalities use the map for the maintenance of the public domain (parks, roads including the road-inventory, etc.), construction, and planning. The municipalities generally require a map with a full coverage. The accuracy requirements differ for the various elements on the map and are for example much higher for buildings than for green belts.

From this overview it is evident that the objectives and requirements of the various participants are quite different. In The Netherlands this has resulted in the situation where two kinds of specifications exist for the large-scale base map (Salzmann, 1995). Most provinces use the so-called 'standard' base map (see Figure 1).
The required accuracy of the map is stated in terms of relative precision. In rural areas the relative precision between two well defined points has to be better than $40\sqrt{2}$ cm, in built-up areas better than $20\sqrt{2}$ cm (Osch, 1991).

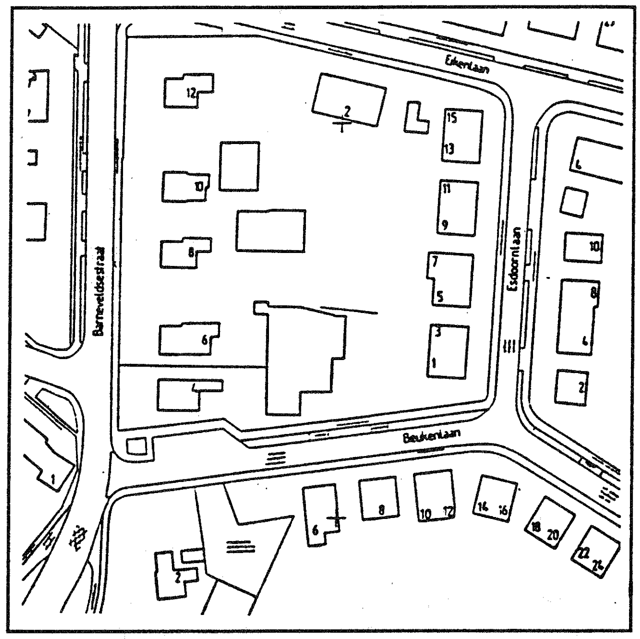

Figure 1: Fragment of the large-scale base map of the Netherlands (1:1000; not to scale).

3. GEOMETRIC QUALITY ASSURANCE

Geometric quality consists of two components, namely precision and reliability. Precision of coordinates is described by a variance-covariance matrix or derived quantities such as standard deviations and error ellipses. Reliability is often described by internal and external reliability parameters. These parameters contain information on the size of an error in the observations that can be detected by statistical testing, and information on the effect of an undetected error of this size on the results, usually the coordinates of the points in the terrain. Reliability is only defined if a redundant measurement set-up is used and statistical testing is applied.
In the HTW a distinction is made between the quality of the product (i.e. the map) and the process (e.g. photogrammetric mapping). The quality of the map is described by means of the relative precision between points. The precision contains two elements. To a large extent the relative precision is due to the measurement process and the subsequent data processing which results in the map coordinates. The second component is the precision with which a point can be pointed out in the terrain: the so-called precision of point definition. The resulting relative precision finally is a function of both components. The reliability of map coordinates is not explicitely described but warranted during the production process. In the HTW it is advocated to guarantee the reliability of a map implicitely by providing guidelines for the production process. If the reliability is warranted the relative precision is a good and sufficient measure to quantify the geometric quality of a map.

3.1 Precision

Talking about the precision of photogrammetric mapping we have to distinguish between the triangulation phase (followed by the block adjustment) and the plotting phase of a photogrammetric project. In both stages the quality of the imagery is decisive for the precision of the measurements. In the triangulation phase the points to be measured are well defined point-symmetric features showing high contrast. Although the precision that can be obtained using signalised points is somewhat better, so-called natural points are preferred from an efficiency point of view. For signalised points a measuring precision of 5 μm in the photographs (or digital images) is required. For natural points the measuring precision should not degrade to more than 6 μm standard deviation.
The precision of manual measurements in digital images is about ¼ of a pixel standard deviation for signalised points, if the photogrammetric workstation provides appropriate functionality (image zooming with e.g.

bilinear interpolation). Using automatic matching procedures a precision of about 0.1 pixel can be achieved on well-defined points. With a pixel size between 10 and 20 μm the (geometric) precision of the photogrammetric scanner is the limiting factor for the precision of the measurements when matching is applied.

The precision of plotting is dependent on the appearance of the feature in the photograph which varies with its shape and properties such as reflectance. Depending on the characteristics of an imaged feature, a measuring precision between 10 and 20 μm can be achieved (Timmerman, 1982). Using digital images plotting can be performed with a standard deviation in the order of 1 pixel (pixel size between 10×10 μm^2 and 20×20 μm^2; see section 4.1).
In case of plotting it is expected that the quality of the measurements in stereo models is somewhat better than in single photographs due to an improvement of the interpretation of the imagery.
Although we have specified the measuring precision at photo scale (i.e. in the photograph), the precision that can be obtained by photogrammetric techniques depends only partly on the photo scale. The actual precision is more dependent on the correct interpretation of the contents of the photographs. The interpretation is improved considerably by using colour photography. Systematic errors due to interpretation can be characterised by a standard deviation in the order of 5 to 10 cm at terrain scale.
To safeguard a good interpretation a factor 3 is chosen for the magnification from photo scale to mapping scale. This results in the use of two photo scales. Photo scale 1:3000 is used for built-up areas and 1:6000 for rural areas. With this approach the precision obtained is somewhat better than the criteria for the base-map.
The measuring precision (at photo scale) is somewhat better for the 1:6000 photography. The image quality of the 1:3000 photography could be slightly degraded as a result of image motion, if not (fully) compensated by FMC, or defocus (a 30 cm lens is used at a flying height of 900 m).

In 1994 a pilot project took place in which a smaller photo scale was tested for the production of the large-scale base map of The Netherlands (Mulder, 1994). The applied photo scales were 1:5000 instead of 1:3000 in built-up areas and 1:12000 instead of 1:6000 in rural areas. This reduction in photo scale resulted in a reduction of the costs of 30% compared to the conventional production of the standard GBKN. The geometric quality of the resulting map meets the GBKN-requirements. Unfortunately the photo scale was not the only difference with the production of the standard GBKN: the map contents was reduced as well. Because of this and the fact that no comparison is made with conventional GBKN-production in the same area, final conclusions on costs, contents or quality can not be drawn.

4. STANDARDS FOR THE PHOTOGRAMMETRIC PRODUCTION PROCESS

The photogrammetric production process is split up in three major steps, one data acquisition step and two data reduction steps (see figure 2):

1 flightplanning and photoflight;
2 (aero)triangulation and block adjustment;
3 plotting and field completion.

Although the HTW does not prescribe in detail how the mapping should be performed, it sets standards and guidelines in order to warrant the quality of the resulting digital map. We will discuss the main standards for each step.

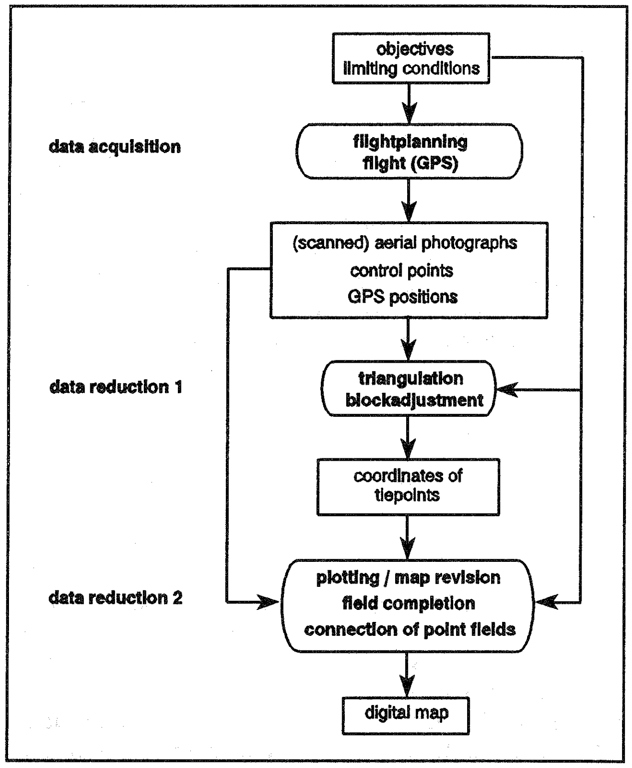

Figure 2: The process of photogrammetric mapping

The quality of the result of the photogrammetric production process is primarily warranted through the standardization of the process. This standardization has not been built from scratch. The (former) photogrammetric department of the cadastral agency and other institutions in The Netherlands issued guidelines for their photogrammetric mapping, but sometimes these guidelines differ considerably from one another. The guidelines presented in the HTW are a unification of the existing guidelines.

A major aspect of the standardization is the introduction of quality control using a testing procedure in every step of the process. Although the criteria (tolerances) used in these procedures are quite strict, they are chosen in such a way that they can be met in production environments.
For the statistical testing of the block adjustment a level of significance of 0.1% is used for the one-dimensional test or w-test. Because the so-called B-me-

thod of testing is adopted, the critical value of the overall model test is depending on the degrees of freedom of the adjustment (Baarda, 1968).
To set the criteria for e.g. testing in the orientation procedures the assesment of the precision of photogrammetric measurement in section 3 is used as a starting point. The criteria for these tests are set to two times the standard deviation of the quantity being tested. In other words: a confidence level of 95% was adopted. It is assumed that only normally distributed quantities are involved.

In the sections to follow each part of the photogrammetric process is briefly discussed with emphasis on its guidelines. In the plotting phase a distinction is made between mapping (production of a new digital map) and map revision. If digital photogrammetric workstations are deployed there is no fundamental difference in the procedures or the quality control. However, in case of map revision in flat terrain 'mono-plotting' is accepted as an efficient technique for map revision. The last step of all surveying processes is the connection of point fields. In case of photogrammetric mapping this is the integration of the newly plotted data with the existing map. In the HTW a separate chapter deals with this often undervalued step.

4.1 Photoflight

The execution of the photoflight is the bottleneck of the photogrammetric process, as there is only a limited number of days available for good photography (ASPRS, 1995). The quality of the aerial photographs is crucial for the mapping process and the quality of the digital map. In figure 3 the first part of the photogrammetric process - the data acquisition - is depicted. The two major parts are the photoflight itself and the setting-up of ground control, possibly in combination with the computation of the coordinates of the projection centra from GPS phase observations. The control points are usually measured by GPS in a separate ground control survey. The positioning of the camera by GPS is only advantageous if it is difficult to establish and measure control points in the terrain (Burman, 1995), which is rarely the case in The Netherlands. One often uses natural control points. Instead of signalising points in the terrain, suitable well defined points are chosen from the photographs. Points that are visible in several photographs can usually also be measured by GPS.

The guidelines for the photoflight (and flightplanning) include for instance:

- specification of flying conditions (weather, time of the year, elevation of the sun);
- photo scale (dependent on map scale);
- overlap (60% in flying direction, 30% between strips);
- tolerances for deviations of the flightplan;
- the location of ground control points.

If GPS is used to determine the positions of the projection centra it is advised to fly two strips perpendicular to the block that contains control points only in its corners. With the current developments in GPS-positioning (such as on the fly ambiguity resolution) it is expected that these extra strips will be superfluous in the near future.

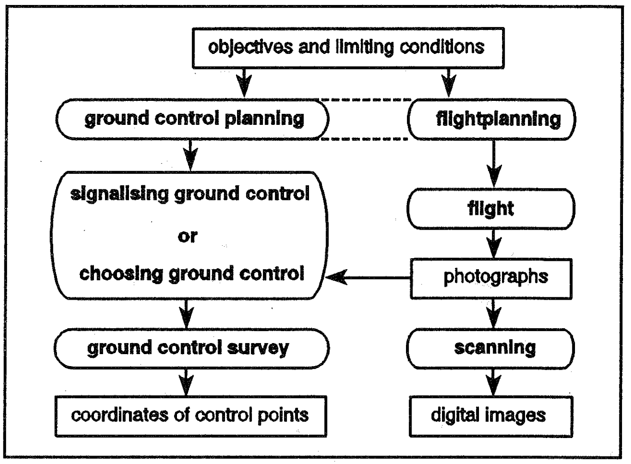

Figure 3: The data acquisition step of the photogrammetric process.

In the digital photogrammetric process scanning is a critical operation because it can result in geometric and radiometric distortion of the information in the photographs. Therefore guidelines have been developed for the scanning of aerial photographs.
These guidelines are split up in guidelines for the photogrammetric scanner and guidelines for the scanning result: the digital aerial photograph. The main requirements for the scanner and the resulting digital image are:

- geometric precision of 5 μm standard deviation or better, independent of the pixel size;
- the pixel size is between 10×10 μm^2 and 20×20 μm^2, allowing good interpretation.

A number of checks on the geometry and radiometry of the image is provided in the HTW. One of the checks on the geometry is part of the interior orientation procedure (see next section).

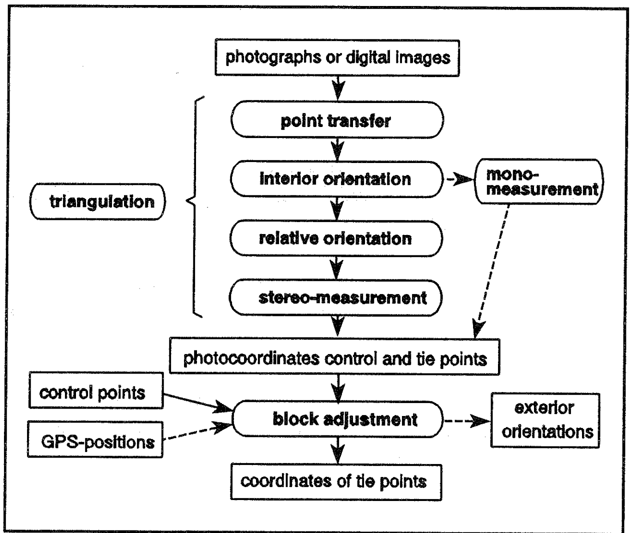

Figure 4: The process of triangulation and blockadjustment.

4.2 Triangulation and block adjustment

In figure 4 the process of triangulation and block adjustment is visualised. For the triangulation step of the photogrammetric process standards have been formulated for e.g. the number of tie points to be measured and their location in the aerial images in the so-called *Von Gruber* locations. The interior and relative orientation are part of the triangulation. The standards for the orientation steps are summarized in table 1. The number of observations has to be at least twice as large as the number of parameters involved.

The standards for the bundle block adjustment incorporate specifications for the functional and stochastic model to be used. As far as the functional model is concerned the bundle method is preferred over the independent model method. The adjustment software has to include statistical testing in the form of the so-called data snooping method.

	interior		relative	absolute	rectification
# parameters (p)	4	6	5	7	8
# points	4	8	12	12	12
# observations (o)	8	16	12	36	24
redundancy (o/p)	2	2.7	2.4	5	3
criterion (2 σ)	10 µm		10 µm	$2\sqrt{(\sigma_{m2} + \sigma_{c2})}$	

σ_{m2} : measuring precision σ_{c2} : control point precision

Table 1: Criteria for the orientation steps

4.3 Plotting and field completion

The plotting and the field completion are the most time-consuming steps. Mostly stereo-plotting is used (depending on the requirements even in the relatively flat terrain of The Netherlands stereo-plotting is necessary). Stereo-plotting greatly enhances the interpretation and thereby the quality of the mapping. Superimposition is used to monitor the progress and to check the completeness of the mapping.

It is advised to register geometric relations such as parallelity of lines or buildings being square during plotting. These relations should not be applied in the plotting phase, but processed in one go with the information gathered during field completion. Depending on the method used for combining the plotting result with the existing map (the connection of point fields), geometric relations should not be applied as a part of the field completion, but integrated in the adjustment for the connection of point fields.

Map revision. For map revision in built-up areas with flat terrain a monoscopic digital approach can be advantageous. After scanning the images are rectified using available natural control points. The criteria for this procedure are listed in table 1. Mono-plotting is then combined with super-imposition. This relatively new approach is very efficient and for certain elements of the map it meets the accuracy requirements in many parts of the country.

The pilot project mentioned in section 3 included a test using mono-plotting in combination with super-imposition of the cadastral map (Mulder, 1994). Making use of the existing cadastral map resulted in savings of some 40%. Of course these savings will depend on the correspondence between topographic features and parcel boundaries. The costs roughly equaled the costs of the same test with stereo-plotting instead of mono-plotting. The geometric quality of the mono-plotting was not as good as the quality of the stereo-plotting; the GBKN-requirements were not met in this test. The applied photo scale is one of the reasons (1:5000 instead of 1:3000 in built-up areas and 1:12000 instead of 1:6000 in rural areas). Height differences could have played a role as well. It is expected that the precision can be improved for instance by using a smaller pixel (after resampling the pixel size used was 30 μm).

Field completion. The goals of the field completion phase of a photogrammetric project are the completion of the map and a check on the map contents. Field completion consists of:

- preparation;
- field work;
- updating of plotting results.

For the preparation of the field work (colour) plots are made. In figure 5 plot samples are shown before and after field completion. The field work normally includes the gathering of semantic information and terrestrial measurements, for example the measurement of roof eaves. The precision of these measurements should correspond to the precision of point definition of the points involved. In this way the precision of the final map will not degrade (significantly) due to field completion.

Updating the plotting result includes the processing of the terrestrial measurements and the integration of the

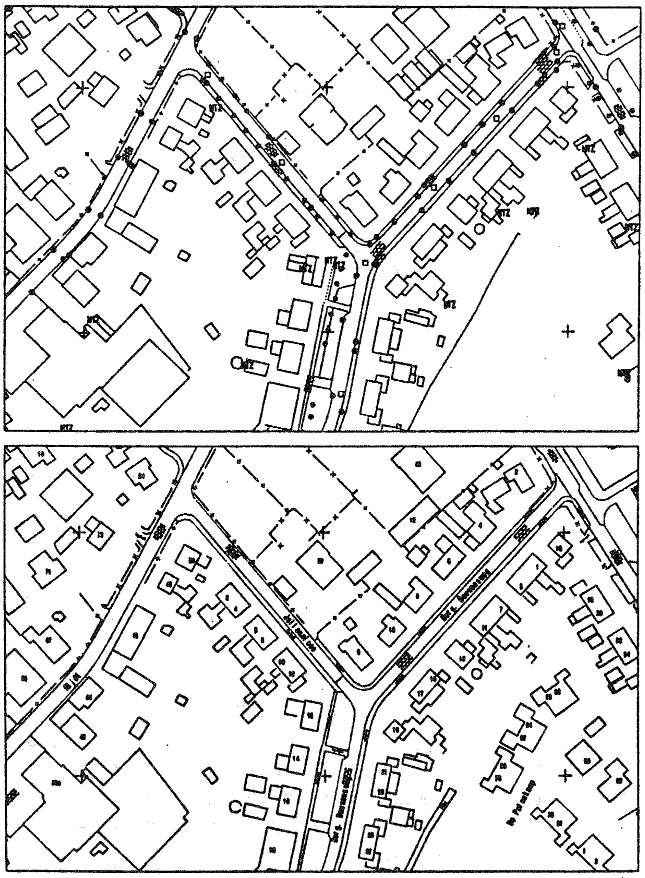

Figure 5: Map before (top) and after field completion.

resulting coordinates and the rest of the information that has been gathered. Geometric relations can be applied at this stage or as a part of the computation for the connection to the existing maps.

6. CONCLUDING REMARKS

This paper contains only a brief sketch of the contents of the parts on photogrammetry and quality assurance of the new manual for the technical activities of the cadastral agency of The Netherlands. The standards and guidelines for new aspects of photogrammetric mapping in The Netherlands have been emphasized, e.g. the use of digital photogrammetry and mono-plotting for map revision.
Applying mono-plotting one should be aware of the effects of height differences on the position of the features in the map, even in a flat-looking country like The Netherlands.
The possibilities of a smaller photo scale (currently a factor 3 between map and photo scale is adopted) needs further investigation. With the current contents and precision requirements for the large-scale base map, image interpretation is the limiting factor for the photo scale.

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