AUTOMATIC TIE POINT EXTRACTION IN AERIAL TRIANGULATION

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ABSTRACT

A new conceptual division of the automatic tie point measurement process into tasks is presented. An important feature in this approach is that attention is paid to the accuracy questions and the treatment of problems in tie point extraction. A system for automatic tie point measurement, which is under development at the Finnish Geodetic Institute, is outlined.
An empirical investigation on the number, distribution and completeness of the tie point observations was carried out. The OEEPE test block Forssa with 30 μm pixel size was used as test data. The investigated factors affected especially the height accuracy. The accuracy of the block improved with an increasing number of observations, but only up to a certain limit. The 5x5 distribution of tie point areas gave only slightly better accuracy than the 3x3 distribution. The accuracy of the block deteriorated with decreasing completeness of the observations. The RMS errors in the check points were in the best case, when using automatic tie point observations: X: 1.8 cm, Y: 2.3 cm and Z: 3.7 cm. The results are promising. There is reason to believe that the accuracy can be further improved.

1. INTRODUCTION

During the last years, automation of the tie point measurement process has been a popular research topic among photogrammetrists. Quite a number of approaches with high automation level have been developed.

The common idea of the systems seems to be as follows. First, the areas where tie point extraction will take place are defined. Corresponding points are measured in these areas using image matching. Because the quality of the matched points is unknown and may be poor, a huge number of tie points is measured to achieve good accuracy. Interactive measurement is used in problematic cases, which arise because of failures in image matching.

There are questions concerning this approach. First, the level of automation is questionable, because the rate of failures is non-deterministic. Second, there are also uncertainty concerning the accuracy and the reliability of a block. Previous results, see (Honkavaara and Høgholen, 1995), show that the accuracy of the block does not improve infinitely with an increasing number of observations.

To handle these questions, the following conceptual division of the tie point measurement process into tasks is suggested:

1. Tie point area definition.
2. Corresponding point definition.
3. Block adjustment and point selection.
4. Quality control.
5. Treating the unsuccessful tie point areas.
6. Process flow.

These tasks are not necessarily separable, but may be combined.

The research activities on automatic tie point measurement have been concentrated mainly on tasks 1 and 2. Anyway, it is clear, that in order to make reliable, accurate and fully automatic tie point measurements all of the tasks should be dealt with.

The tasks in the tie point extraction process are described and the system for tie point measurement being under development at the Finnish Geodetic Institute (FGI) is shortly outlined in Section 2 (more thorough description is given in (Honkavaara and Høgholen 1995)). Empirical results about the effect of the number, distribution and completeness of the tie points are presented in Section 3.

2. AUTOMATIC TIE POINT MEASUREMENT

2.1 Tasks in tie point measurement

2.1.1 Tie point area definition

It is usually sufficient to extract tie points in a limited number of distinct, homologously distributed locations, so called tie point areas. For stability reasons it is important to select tie point areas so that there exists a maximal number of overlapping images. For instance, in a typical photogrammetric block with 60% forward overlap and 20-30% side overlap, 6-fold overlaps are quite frequent. The tie point area distribution is discussed in Section 2.2.1.

The paradox on defining tie point areas is that the exterior orientation of the images as well as the topography should be known. There exist different methods for tie point area definition with varying complexity, see overview in (Förstner 1995). The most simple methods use only approximate values of the exterior orientations and assume smooth terrain. The more sophisticated methods define the overlap areas by using progressively refined image fingerprints (defined by using orientation parameters and terrain heights determined during the tie point extraction process). A high level of automation can be achieved.

In the system at FGI the tie point areas are determined in two steps. First the overlap areas are coarsely defined by using approximate coordinates of the perspective centres. The coordinates of the tie point areas are usually not accurate enough for tie point extraction, because the approximations may be rough and there are normally variations in the elevations of the terrain. The coordinates are therefore refined by image matching. In the refinement, cross correlation with a special matching strategy on low resolution images is used. Possible gross errors are detected in the block adjustment and additional observations are carried out interactively. The approach has been proven to work well, for instance in the OEEPE test block Forssa, only 2.2 % of the automatically measured observations were erroneous, see (Honkavaara and Høgholen 1995).

2.1.2 Corresponding point definition

The tie points are measured in tie point areas using image matching. There are different matching methods available, from techniques using local image information, like least squares matching (LSM) and feature based matching (FBM), to global techniques, see overview in (Förstner 1995).

At FGI, the approach selected for tie point extraction is based on the one developed by Tsingas, see (Tsingas 1992, 1994). The tie points are first extracted using multiple image FBM. Because of the rather low accuracy of FBM, the extracted coordinates are refined by LSM. The Tsingas' method is further refined to achieve higher speed and good success rate with multiple matches, see (Honkavaara and Høgholen 1995). In order to get good enough approximate values for the matching process a multiresolution image pyramid with 3 layers (scales 1:16, 1:4 and 1:1) is used.

2.1.3 Block adjustment and point selection

The block adjustment can be seen as an important part of the tie point measurement process. In the block adjustment, in addition to solving the unknowns of the mathematical model, also the possible gross errors are detected.

Automating the block adjustment when using interactive measurements is treated in (Sarjakoski 1988). Automatic tie point measurement gives new features to the block adjustment like:

1. there are considerably more observations,
2. the quality of the observations is unknown and
3. there are more gross errors.

It is important to investigate if the techniques developed for interactive measurement are sufficient when using automatically measured observations. The experience gained so far from block adjustments with automatic tie point observations is that in some cases the use of additional parameters have negative influence on the accuracy of the block, see (Honkavaara and Høgholen 1995). Additional parameters are sensitive to inaccurate observations and poor distribution of the tie points. Tests have shown that correct weighting is critical as is the type of additional parameters to be used.

In the system at FGI the whole block is processed in a single block adjustment using a separate adjustment program. The adjustment procedure does not differ from the one used with interactive measurements. Block adjustment will be implemented as a part of the tie point extraction program. This means that block adjustment will be performed also on sub blocks, which makes the quality control easier.

More observations are measured than needed in the tie point extraction process. Consequently, an important task after the block adjustment is to select a sufficient number of relevant observations. At the moment the selection process relies on heuristic ideas. The criteria in the selection are: 1) importance (number of observed images with insufficient number of observations), 2) completeness (maximising the number of observed images), 3) distance from other selected points (good distribution) and 4) distinctness (a minimum requirement is that the LSM windows do not cover each other).

2.1.4 Quality control

In the traditional interactive aerial triangulation process, the operator ensures that there exists a sufficient number of good observations. The final quality control is performed in the block adjustment.

In the automatic measurement process, in addition to checking the statistics, also the adequacy of the observations in each tie point area have to be checked, i. e.:

1. *The number of observations in each image is sufficient.* It has to be checked, that there are enough observations in each of the overlapping images.
2. *The completeness of the observations is sufficient.* It is not enough to check only the number of observations in each of the images. As mentioned in Section 2.1.1, to achieve stability in the block, also matches on multiple images are needed.
3. *The distribution* of *the observations is sufficient.* The tie point observations should have proper distribution.

Sufficiency, completeness and distribution of the tie point observations are under investigation at FGI. They are discussed in Section 2.2 and empirical results are presented in Section 3.2.

2.1.5 Processing of the unsuccessful tie point areas

The tie point areas which failed in the quality control have to be treated. In general, the matching may fail because of difficult objects (difficult 3D-object, monotone object, water, forest, obstacle etc.) or poor imagery (radiometric differences etc.). The matching method affects the rate of failures.

Different actions can be carried out in the failed areas, depending on the reason for failure:

1. *Regard the failure as non-influent.* The failure does not deteriorate the accuracy.
2. *Search for better location for matching.* Regardless of failed matches in certain locations, there exists good areas for matching for the given image combination in the overlap area.
3. *Search for optimal image combinations.* There exist no match for the given combination of images in the overlap area, but there exist matches for some other combinations.
4. *Stop matching with impossible images.* Matching will not succeed in the overlap area in some, or in the worst case in all of the images.
5. *Select another matching method.* Matching may succeed using another method, for instance, by interactive measurement.

To perform the correct action, intelligence is required from the system. This task is solved interactively in the existing systems.

In the system at FGI, the checking process is also interactive. The reason for failure is checked and one of the actions mentioned above is carried out.

2.1.6 Process flow

Knowledge on how the tie point extraction is progressing is realised in the process flow. Different tasks are evoked using this knowledge and information gained during the tie point extraction process.

At the system at FGI the basic process flow is realised at the moment as follows:

1. Define the proper locations for tie point extraction, see Section 2.1.1.
2. Extract a large number of tie points in each tie point area, see Section 2.1.2.
3. Perform block adjustment and select a sufficient number of points in each tie point area, see Section 2.1.3.
4. Check the quality of the block, see Section 2.1.4.
5. Process the unsuccessful tie point areas, see Section 2.1.5.
6. Iterate steps 3-5 until the quality is satisfactory. Complete with final block adjustment.

2.2 About distribution, number and completeness of the tie point observations

Important factors in the tie point extraction process are distribution, number and completeness of the tie point observations. Appropriate values for these factors depend on the imagery and measurement method used and of course on the accuracy requirements, but they are not exactly known. They are briefly discussed below.

2.2.1 Distribution of tie point observations

The concept of the distribution of tie point observations can be treated on global and local levels. Global distribution means the distribution of tie point areas on the image. Local distribution means the distribution of numerous tie point observations in the tie point area. In the following, global distribution is discussed.

When using conventional aerial imagery and interactive measurement, it is sufficient to extract tie points in the Gruber positions (3x3 tie point area distribution). This has been considered, though not proven, to be sufficient also in the automatic case, see (Schenk 1995, Tsingas 1992). On the other hand, the measurement of extra points can easily be carried out using automatic methods. It is therefore of interest to test if a more dense distribution of tie point areas will lead to an increase in the accuracy of the block. A 5x5 distribution on the images was tested and the results are presented in Section 3.2.2.

2.2.2 Number of tie point observations

The number of observations can be huge in automatic tie point extraction. The main reasons for this are: 1) it is usually easy to measure a large number of observations, 2) the quality of the observations is unknown (matched objects may be poor which concerns all measurement methods), and better accuracy is achieved by increasing the number of observations and 3) the accuracy of some commonly used image matching methods is poor (FBM).

a)

Strip 1	Image *1*	Image *2*	Image *3*
Strip 2	Image *4*	Image *5*	Image *6*

b)

Neighbour-hood	Image combinations
4	*<1, 2, 4, 5>, < 2, 3, 5, 6>*
3	*<1, 2, 4>,<1, 2, 5>, <1, 4, 5>, <2, 4, 5>,* *<2, 3, 5>,<2, 3, 6>,<2, 5, 6>, <3, 5, 6>*
2	
inside strip	*<1, 2>, <2, 3>, <4, 5>,<5, 6>,*
between strips	*<1, 4>,<2, 5>,<3, 6>*

Figure 1. Splitting a 6-fold tie point area. a) Overlap area: two strips with 3 images. b) Splitting to 4-, 3- and 2-neighbouring image combinations.

The question about the number of tie point observations is often too much simplified: the more observations the better results. 200-300 observations/image seems to be commonly used. There are evidences that an increasing number of observations does not necessarily lead to better results. One important reason for this is that not all observations have any significant influence on the result. The effect of the number of observations was tested and the results are presented in section 3.2.1.

2.2.3 Completeness of the tie point observations

As mentioned in Section 2.1.1, to achieve stability in the block, matches on multiple images are needed. The problem is that matches especially in 6-fold tie point areas may easily fail. This is because the overlap area tends to be small and there are often big radiometric and geometric differences between the overlapping images, which can not be dealt with using known image matching techniques, see also 2.1.5.

In some cases tie point areas have to be split. In general, in a n-fold tie point area, there are $\sum_{i=2}^{n}\binom{n}{i}$ different image combinations (for instance, 57 image combinations in a 6-fold area). In practice, successful matches are usually most likely to be found between neighbouring images. In Fig 1. splitting a 6-fold tie point area into 4-, 3- and 2-neighbouring image combinations is shown. The effect of splitting the tie point observations was tested and the results are presented in Section 3.2.3.

3. EMPIRICAL INVESTIGATION

3.1 Test arrangements

3.1.1 Subjects studied

The following subjects were studied: 1) selecting a varying number of points from each tie point area, 2) reducing the completeness of the observations, 3) using 5x5 tie point area distribution and 4) using a tie point extraction strategy combining multiple and pairwise matches. The investigation is not comprehensive, it is meant to give ideas about the effect of some factors.

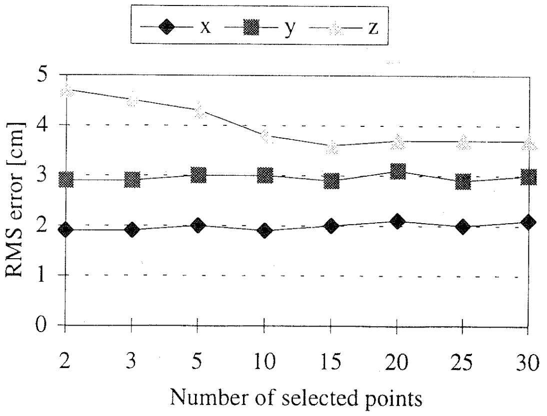

Figure 2. Selecting a varying number of tie points in each tie point area. RMS errors in X, Y and Z in the check points, as a function of the number of selected points.

3.1.2 Test material

The OEEPE test block Forssa was used in the investigation. The block consists of 28 digital monochromatic aerial images in the scale 1:4000 (four strips with seven images in each, 60% forward overlap, 20-40% side overlap, 30 µm pixel size). The images are from an urban area. The control point configuration (14 XYZ) and the check points (50 XY and 41 Z points) were the same as used in the OEEPE test project, see (Jaakkola and Sarjakoski 1994).

A large number of tie points was measured automatically by the system described in Section 2. The same data was used throughout the investigation, with additional measurements in some cases. Also interactive tie point measurements were carried out, for comparison. The fiducial and ground control point measurements were carried out interactively.

In the automatic tie point measurement, 102 tie point areas were selected in the standard Gruber positions. About 80 tie point observations were measured in each of them (in the image pyramid layers, respectively 4, 4 and 5 tie points).

The RMS errors in the check points, when using automatically measured tie points, were: X: 2.3 cm, Y: 3.0 cm and Z: 3.5 cm. When using interactively measured tie points, the RMS errors were: X,Y: 2.3 cm and Z: 3.3 cm.

When using automatically measured tie points, the RMS error in Y was considerably worse than in X, with a difference of almost 1 cm. This phenomenon was not present when using interactively measured observations, so the reason is likely to be the existence of poor observations.

3.2 Results and discussion

3.2.1 Selecting a varying number of points from each tie point area

A varying number of points (2, 3, 5, 10, 15, 20, 25 and 30) was selected from the test data in each tie point area in each image. In the selection process, the criteria presented in Section 2.1.3 were used.

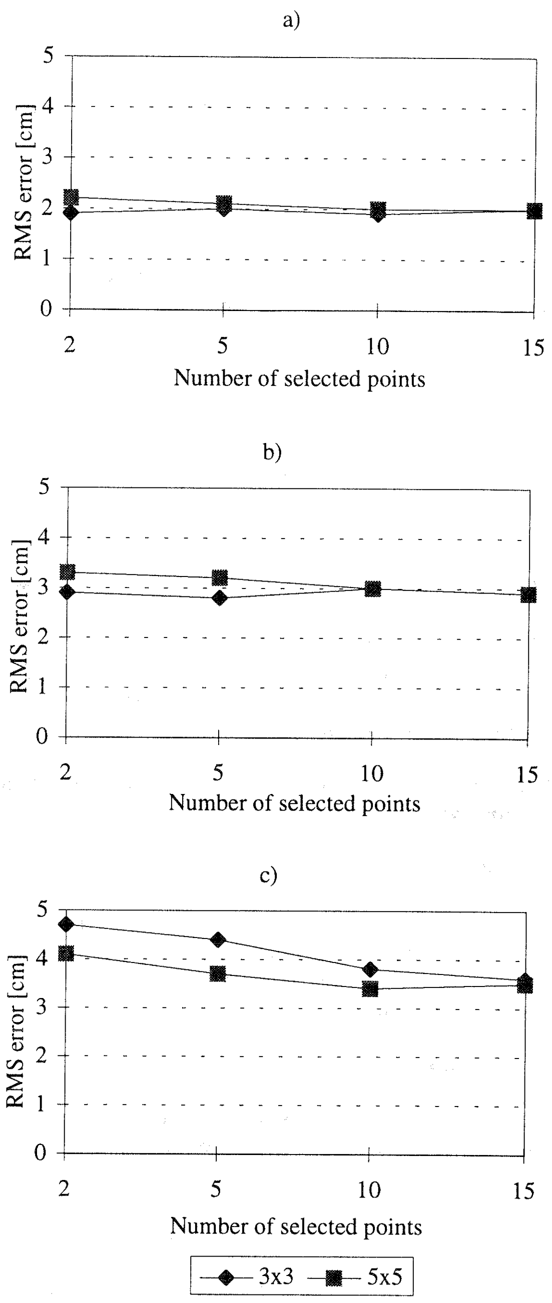

Figure 3. Using 3x3 and 5x5 tie point area distributions. RMS errors in the check points as a function of the number of selected points in each tie point area.

Some comments should be made about the selection process. The distances between the selected points decreased as the selection process proceeded (the minimum distance between points was 12.5 pixels). In general the required number of observations was found, but not in difficult cases (which seldom occurred). The completeness of the observations was good when up to 10 points were selected, thereafter it was slowly decreasing. Due to this, the significance of the selected points will probably decrease as the selection process proceeds.

The RMS errors in the check points are presented in Fig. 2. The following conclusions can be drawn:

- The number of points had no influence on the accuracy of X and Y. On the other hand, the number of extracted points

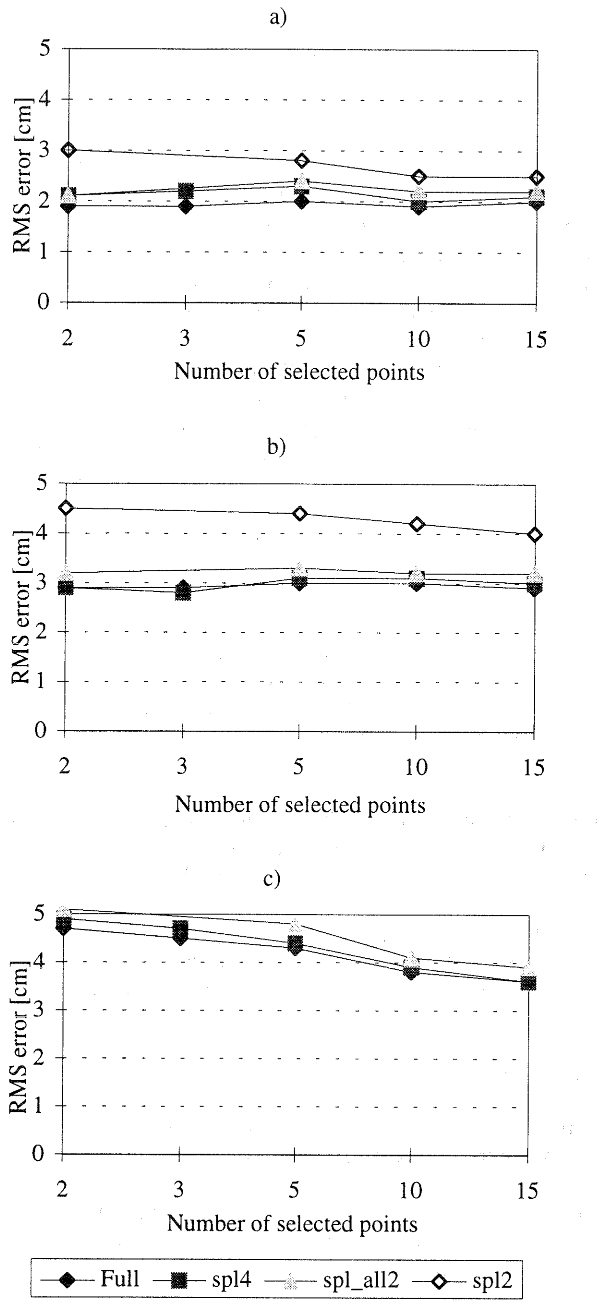

Figure 4. Reducing completeness of the observations. RMS errors in the check points as a function of the number of selected points in each tie point area. (*Full:* full completeness, *spl4*: splitting to 4-neighbouring combinations, *spl_all2*: splitting to all possible pairwise combinations and *spl2*: splitting to 2-neighbouring combinations). In case *spl2*, the RMS errors in Z were in the order of 10 cm and are not shown in the figure.

had significant influence on the accuracy of Z, but only up to a certain limit.

- It looks like 15 points per tie point area was close to an optimum under these conditions, giving RMS errors: X: 2.0 cm, Y: 2.9 cm and Z: 3.6 cm. Any further increase in the number of points did not give better results.

3.2.2 Using 5x5 tie point area distribution

A 5x5 tie point area distribution was tested to see if it has any effect on the accuracy of the block.

The RMS errors, when using all observations were: X: 2.2 cm, Y: 3.1 cm and Z: 3.6 cm. They were in the same order as for the 3x3 distribution (see Section 3.1.2). The results, when selecting a varying number of points in each tie point area, are presented in Fig. 3 together with the 3x3 case. It can be concluded that a denser distribution had no significant effect on X and Y. An effect could though be seen on Z, which was clearly better in the 5x5 case if relatively few points were selected in each tie point area. When the number of points in each tie point area reached 15, Z was practically equal in both cases.

3.2.3 Reducing the completeness of the observations

In Section 2, a problem with matching failures and reduced completeness was presented. The effect of reducing the completeness of the tie point observations was empirically tested. Observations selected in Section 3.2.1, were split into 2- and 4-neighbouring observations (see Fig. 1) and to pairwise observations in all possible combinations.

The results are presented in Fig. 4, together with the complete case. It can be concluded that:

- The accuracy of the block was decreasing when the completeness was reduced, as expected.
- The accuracy of the case with 4-neighbourhood was practically as good as the accuracy of the complete case, when a sufficient number of observations (>10) was used in each tie point area.
- The accuracy of the case with pairwise observations in all combinations was better than expected. It was only slightly worse than the case with complete observations.
- The case with 2-neighbouring observations was clearly worse than the other cases. Especially the RMS errors in Z were bad (in the order of 10 cm, not shown in Fig. 4).

3.2.4 Combining pairwise and multiple matches

In the system at FGI, when measuring tie points, the goal is to make as complete observations as possible (maximal number of overlapping images), which is not necessarily an optimal approach. This is mainly because the local distribution of tie points may get poor in difficult overlap areas. This was tested by combining a varying number of multiple matches (selected in section 3.2.1) with a varying number of separately performed pairwise matches (carried out in the Gruber positions between 2-neighbouring images).

When combining all the measured pairwise observations with the selected 3 points case, the RMS errors were: X: 2.0 cm, Y: 2.4 cm and Z: 3.6 cm. Y was clearly better, and X and Z on the same level as for the best cases using only multiple observations.

The results, when combining a different number of pairwise and multiple observations are presented in Fig. 5. The following can be concluded:

- Adding observations affected especially cases where only a few multiple points (2,3 or 5) were selected. The accuracy in these cases was better for X and Y (especially in Y) than in cases where 10 or 15 multiple points were selected.
- Using a large number (10-15) of multiple observations or using a few (for instance, 3) multiple observations and adding more than 10 pairwise observations, gave about the same accuracy in Z.

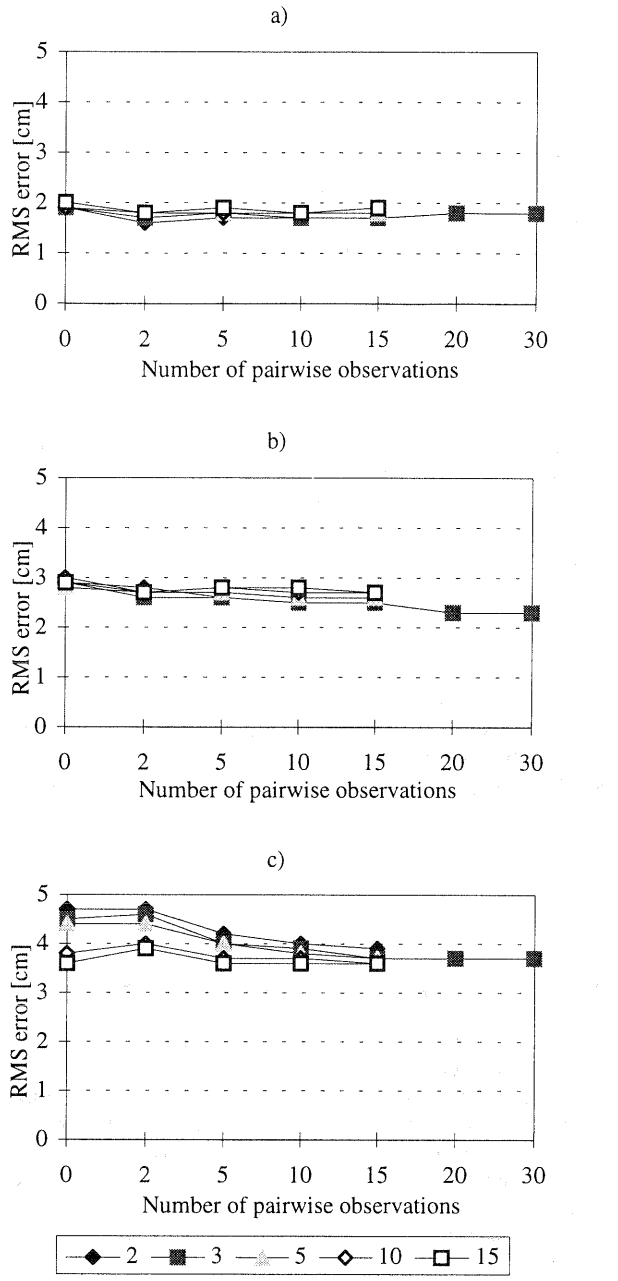

Figure 5. Combining multiple and pairwise observations. RMS errors in the check points when a varying number of multiple observations was selected in each tie point area, as a function of the number of added pairwise observations.

- Slightly better accuracy was achieved when combining multiple and pairwise observations, than when using only multiple observations.

4. CONCLUSIONS

In this paper, automatic tie point extraction has been discussed. A new conceptual division of the tie point measurement process into tasks is presented. The approach pays attention to the accuracy questions and the treatment of problems in the tie point measurement.

The effect of the number, completeness and distribution of the tie point observations was empirically investigated using the OEEPE test block Forssa with 30 μm pixel size. The investigation was not comprehensive, it was meant to give ideas about the effect of some factors.

The factors affected especially the height accuracy. The accuracy of the block improved as the number of observations increased. This effect was only valid up to a certain limit (15 points in each tie point area). The reason for this is either limited accuracy of the method or more likely, that there were no more significant observations. 3x3 and 5x5 distributions of tie point areas were tested. The 5x5 distribution gave slightly better results. The accuracy of the block deteriorated when the completeness of the observations decreased, though the accuracy of the block using 4-neighbouring observations was nearly as good as the accuracy using complete observations. A new strategy for tie point measurement, carrying out both multiple and pairwise matches, gave good results.

The RMS errors in the check points were in the best case, when using automatic tie point observations: X: 1.8 cm, Y: 2.3 cm and Z: 3.7 cm. The accuracy was on the same level as when using accurate interactive measurements (X,Y: 2.3 cm and Z: 3.3 cm). The result with automatic measurements is very promising, because it seems that the accuracy can be further improved as the knowledge about carrying out and handling the observations increases.

Important topics for further investigations are the factors affecting the accuracy and reliability of the block, like distribution of and number of tie point observations, usage of additional parameters and matching strategies (for instance, combining multiple and partial matches). Investigations using imageries of different scales and types are needed. It is also important to incorporate intelligence in the systems, to increase the level of automation.

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