ACCURACY OF SUPERIMPOSITION

A. van Voorden and M. van Persie*
Delft University of Technology,
Faculty of Geodetic Engineering,
Thijsseweg 11, 2629 JA Delft,
The Netherlands

ABSTRACT: Superimposition can in principle be used for the detection of errors in coordinates of features which are stored in a database.
For the error detection three aspects are important:
1. The width of the lines which are superimposed on the aerial photograph(s).
2. The accuracy of superimposition through the whole stereomodel at the position of the measuring mark.
3. The accuracy of superimposition through the whole field of view of the binoculars.

For each of these aspects a testing method has been developed. The test procedures have been used to test three superimposition systems, which are built in analytical plotters of different companies.
In the paper characteristics of the tested superimposition systems are given. The testing methods will be described and the results will be presented.

KEY WORDS: Accuracy, superimposition, algorithm, data base, data quality.

1. INTRODUCTION

Superimposition means the projection of a digital topographical database on one or two photos in the stereo restitution instrument, which implies that photo and data base of an area can be viewed simultaneously.
A short description of superimposition and some characteristics of superimposition systems will be given in chapter two.

In practice superimposition is mostly used to check if the features which are stored in the database are complete and actual.

The aim of the research described in this paper is to determine the superimposition accuracy of different systems. When the accuracy is known conclusions can be drawn to which extend the detection of data base errors is possible. For the determination of this accuracy important are:
1. The superimposition accuracy at the position of the measuring mark through the whole stereo model.
2. The superimposition accuracy around the measuring mark through the whole field of view.
3. The width of the superimposed lines.

To investigate the above mentioned aspects at the Delft University of Technology testing procedures have been developed (Van Persie 1991).
The tests are used to determine the superimposition accuracy of three systems.
These systems are the I.M.A. system of Intergraph, the DSR 15 with the Kriss superimposition system of Leica (Kern) and the P3 with the videosystem of the Zeiss Company.

The developed tests and the test results are described in chapter 3. In chapter 4 conclusions and recommendations are given.

2. SUPERIMPOSITION PRINCIPLE AND SUPERIMPOSITON SYSTEMS

Superimposition is based on the following principles:
1. X, Y, Z coordinates of features stored in the database are transformed with the formulas of perpective projection to the geometry of the photo. For the transformation are used the projection centre coordinates and rotations of the photo on which the database has to be projected.
2. The transformed database is imaged on a screen. The screen image is projected via a system of lenses and mirrors on the photo image.

In figure 1 (Bonjour, 1988) the superimposition principle is shown.

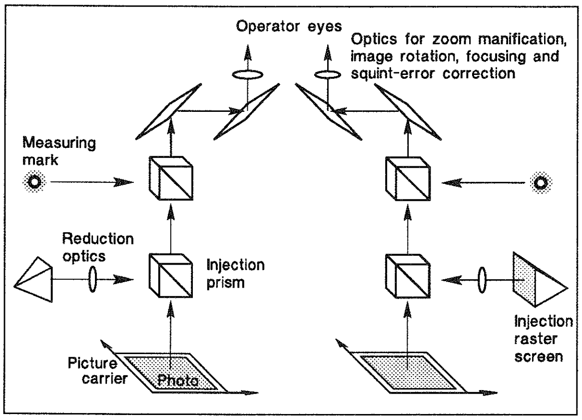

Figure 1. Stereo superimposition system (Bonjour 1988).

* Present address: National Aerospace Laboratory (N.L.R.), Emmeloord, The Netherlands

For different superimposition systems there are a number of variables which influence the superimposition accuracy:

1. In the analytical plotter superimposition can be realized directly in the neighbourhood of the photocarrier or nearby the ocular(s).
   If superimposition has been realized nearby the photo then rotation of the Dove prisms and zooming will have the same effect on the superimposed image and on the photo image. A disadvantage can be that when zooming in, the pixels of the image displayed on the screen are seen more clearly and only the centre of the screen will be used for display.
   When superimposition is realized near the ocular(s) always the whole screen can be used for superimposition and the size of the pixels can be kept small. However, when zooming and when rotating the Dove Prisms the screen image has to be geometrically adapted.
2. Superimposition systems can be equiped with small flat screens or curved screens. When using a curved screen the image has to be corrected for screen curvature. Further the screen can be a raster type or vector type screen.
3. If the database image is projected on one photo only this is called mono-superimposition. When the database is projected on two photographs which form a stereomodel then the database can be viewed in stereo. Stereo superimposition is important when digital height data have to be checked.
   In this research only mono superimposition systems have been used.

   The characteristics of some systems are given in table 1.

3. TESTS FOR SUPERIMPOSTION SYSTEMS

3.1. Introduction

By using two calibration grid plates a practical situation has been simulated.
The simulation date are:
Photoscale 1:3000, c = 150 mm, 60% overlap.
The number of grid points in the stereomodel is 77 (see figure 2).

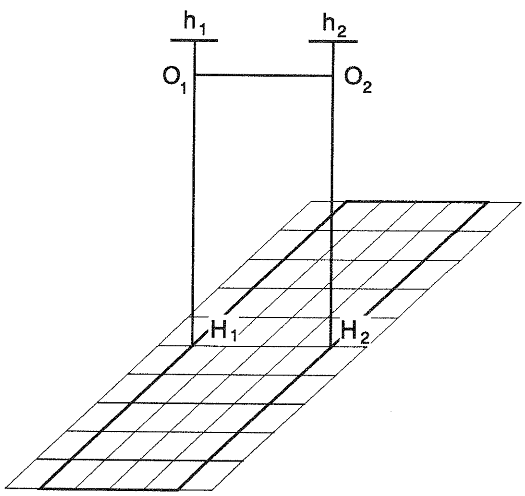

Figure 2. The flat stereomodel.

In order to get height differences in the stereo model the terrain model has been tilted two grads around the x- and y-axis.

	I.M.A.	KRISS	RIVS	Videomap II
mono or stereo superimposition	mono	mono/ stereo	mono/ stereo	mono/ stereo
monochrome or colour	colour	monochr.	monochr.	monochr.
raster or vector screen	raster	raster	raster	vector
screen update per second	60	60	60	60
resolution in photo in microns	20-5	25/50	10	40
superimposision nearby photo or ocular	ocular	photo	photo	photo
memory space in Mb	-	4-16	4-8	1-2

Table 1. Characteristics of some superimposition systems.

The new terrain coordinates have been determined by transformation. After some computations we had to our disposal:

1. X, Y, Z-coordinates of the theoretical terrain.
2. Orientationparameters of the photos, which are in this case two grid plates.
3. Photo-coordinates of the terrain points.

3.2. Test A. Superimposition accuracy at the position of the measuring mark through the whole stereomodel

The aim of test A is to determine by measurement the superimposition accuracy at the position of the measuring mark through the whole stereomodel.

First of all the intention was to use the following procedure:

1. Realize the superimposition of the 77 data base points by using the known photo orientation data.
2. Determine by measurement the photo-coordinates of the superimposed data base points.
3. Determine the superimposition accuracy by comparing the photo coordinates of step 2 with the ideal photo coordinates.

It appeared however that when using the superimposition software of the different available systems recording of photo-coordinates instead of X, Y, Z coordinates is not possible and that for some systems the input of known orientation data give problems. Therefore the following procedure has been used:

1. Input of database coordinates X, Y, Z.
2. Interior, relative and absolute orientation of the grid plates. The coordinates of 6 data base points are used for the absolute orientation.
3. Superimposition of the database on the left photo.
4. Measurement of the superimposed points and recording of the terrain coordinates X^1, Y^1, Z^1.
5. Transformation of X, Y, Z and X^1, Y^1, Z^1 to photo-coordinates x, y and x^1, y^1 with absolute orientation parameters.
6. Determination of the superimposition accuracy by comparing the ideal photo-coordinates x, y with the photo-coordinates x^1, y^1.

When testing the three superimposition systems the database has been superimposed in the left 'photo' with a magnification factor of 10x.

In order to facilitate the work of the photogrammetric operator the superimposed image has been shifted $\pm$ 0.2 mm with respect to the photo image.
The measurements have been executed forwards and backwards. When using system 2 only 66 of the 77 database points could be measured.

After the transformation of X^1, Y^1, Z^1, to the geometry of the photo the obtained photo-coordinates have been averaged.

Then for each system the standard deviations σ_x and σ_y of the mean photo coordinates have been computed, see table 2.

	System 1	System 2	System 3
σ_x	4	7	6
σ_y	4	5	6

Table 2. Measuring accuracy of superimposed data base points. Magnification factor 10. Units in microns at photo scale.

The superimposition accuracy σ_x and σ_y have been computed by using the formula:

$$\sigma = \sqrt{\frac{\Sigma(d - \frac{\Sigma d}{n})^2}{n}} \qquad (1)$$

with d = $(x - x^1)$ for σ_x and d = $(y - y^1)$ for σ_y.
n = the number of points.

Computed standard deviations are given in table 3.

	System 1	System 2	System 3
σ_x	16	10	19
σ_y	21	9	28
n	77	66	77

Table 3. Superimposition accuracy in microns at photo scale at the position of the measuring mark.
n = number of points

After plotting the discrepancies dx, dy for the three systems it appeared that for the systems 1 and 3 the superimposed image has a systematic distortion. For system 1 this is caused by a scale difference with as origin the model centre and for system 3 there is a distortion which is perpendicular to the model base and especially present at the left and right model border.
After repetition of the computation with only the points which lie between the principle points H1 and H2 (see Figure 2) the superimposition accurracy becomes as given in table 4.

	System 1	System 2	System 3
σ_x	12	10	13
σ_y	21	9	22
n	55	55	55

Table 4. Superimposition accuracy in microns at photo scale with 55 points.

When the superimposed images of the systems 1 and 3 are corrected for radial scale distortion from the model centre the standard deviations are respectively:
$\sigma_x = 6\mu$, $\sigma_y = 5\mu$ and $\sigma_x = 14\mu$, $\sigma_y = 13\mu$ at photoscale.

Conclusions:
1. Table 3 shows the standard deviations for the three tested systems. The residual errors showed that no systematic errors are present when using system 2.
2. Table 4 shows the standard deviations when using for superimposition only the model part between the projection centres (Figure 2).
3. The standard deviations for the systems 1 and 3 become smaller when the superimposed images are corrected for scale distortion.

3.3. Test B. Accuracy of the superimposed points in the field of view

The problem when determining the superimposition accuracy outside the centre of the field of view is, that it is not possible to measure superimposed points with the help of the measuring mark. The reason is that the centre of the field of view is determined by the measuring mark itself.
Therefore the following test procedure has been developed.
One of the gridplates in the analytical plotter is replaced by a dense line grid, which has been drawn with an automatic plotting table and has been reduced photographically.
The distance between the gridlines is 200 microns and the width of the lines is 10 à 20 microns.
For recognizability the centre line of the grid has been plotted thicker. The standard deviation of the grid points for an area of 2x2 cm is 2 à 3 microns.
During the test the centre line of the grid is superimposed and by changing the position of the measuring mark the superimposed line together with the gridline is moved in steps of 2 mm to the edge of the field of view. The movement is executed both in horizontal and vertical direction.
The deviations are observed with the help of the dense linegrid by counting the number of grid intervals and interpolation between the grid lines in units of 20 micron (See Figure 3).

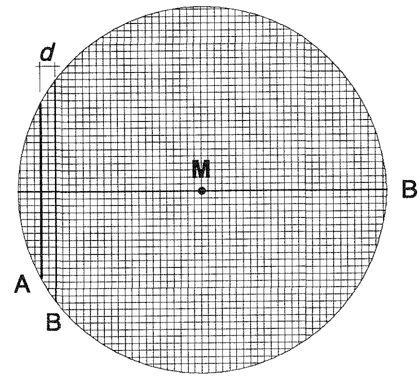

Figure 3. Determination of superimposition deviations. M = measuring mark; A = superimposed line; B = grid lines; d = deviation.

It is assumed that observed deviations are caused by the lens system and the screen and so will be present in the same way through the whole stereomodel. Therefore the measurements are executed only in the centre of the stereomodel. To determine the influence of zooming on the accuracy the test has been executed with different zoom settings.

If the used superimposition systems are not calibrated in an optimal way the following systematic effects can appear:
1. A constant systematic deviation in x and y direction.For the systems of Zeiss and Leica-Kern it is possible to correct for this effect by moving the superimposed image. For the system of Intergraph this is possible by moving the screen or by changing the direction of the cathode ray.
2. A rotation of the superimposed image with respect to the photo. This can be caused by a rotated position of the screen. For the three used systems adjustable screws are present to rotate the screen.
3. Different scale factors in x- and y-direction. This effect can be eleminated by tilting the screen.
4. A constant scale-diffference. By moving the screen further away or nearer by this effect can be eliminated. A limiting factor in this case is the range of the depth of field.

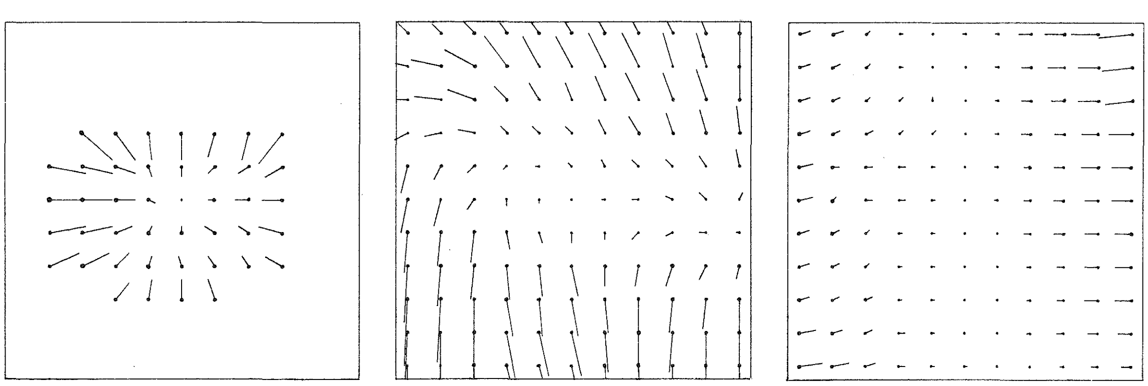

Figure 4. Error patterns of the systems 1, 2 and 3 without correction for systematic deviations. Vector scale: 1 mm = 40 micron.

When processing the measurements it has been assumed that the systems can be corrected for the effects which are described above.
To correct for the systematic deviations a transformation has been applied on the observations with as parameters two shifts, two scale factors and one rotation. Patterns of systematic deviations are given in figure 4.

With different zoom settings the line width is determined at the circle position by setting the measuring mark at two positions of the line (see Fig. 5). Through the knurled character of the lines (raster screen) a measuring mark as large as possible has been choosen. For the computation of the line width it was necessary to determine the diameter of the measuring mark too.

Systems	Zoom	σ_x	σ_y	σ_x^1	σ_y^1	n
1	10x	114	92	24	24	43
	20x	132	80	14	10	12
	40x	74	38	10	10	15
2	5x	170	200	34	36	121
	10x	24	88	20	24	21
3	5x	64	12	22	14	121
	10x	64	10	16	10	75

Table 5. Test B. Standard deviations in microns at photoscale before and after systematic error correction. σ_x, σ_y = before correction; σ_x^1, σ_y^1 = after correction; n = number of measured points.

Table 5 shows that the standard deviations after the correction for systematic errors become considerably smaller. When using a 40 times magnification the smallest residual errors are present in system 1 (σ_x = 10 μ, σ_y = 10 μ). For a zoom factor of 10 times the smallest standard deviations are present in system 3 (σ_x = 16 μ, σ_y = 10 μ).
The conclusion is that for the detection of data base errors all the used systems should be callibrated.

3.4. Test C. Determination of the width of the superimposed lines.

The factors which influence the width of the superimposed lines are the illumination, the line direction and the zoomfactor.
When the superimposed line is strongly illuminated with reference to the photo then the line will be thicker than in the case of a poor illumination. When the line is represented on a raster screen, then horizontal and vertical lines will have a width of 1 pixel. In other directions this can increase to 1,5 pixel.

Considering the above mentioned factors a line pattern as shown in figure 5 has been used for testing.

Because the lines on the screen move in steps of 1 pixel measuring problems occured. To get a good measuring accuracy every point has been measured four times.

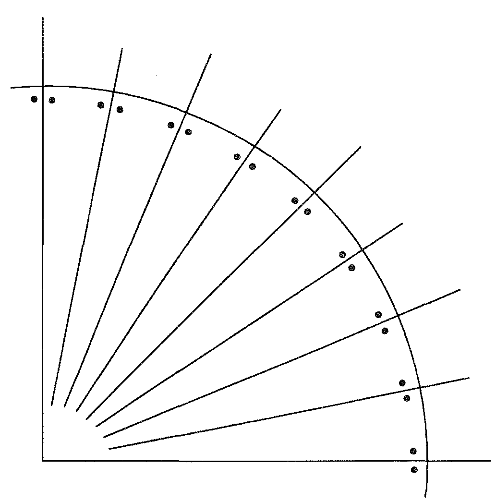

Figure 5. Superimposed line pattern for line width measurements. . = measured point.

In table 6 the line widths and their standard deviations are presented for the different systems and different zoom settings.
Table 6 and figure 6 show that when zooming in with system 1, the line width decreases from 44 to 20 microns. The reason is that superimposition takes place nearby the occulars.
For the systems 2 and 3 zooming takes place nearby the photo and therefore the line width is constant, respectively 25 and 76μ. It was not possible for all systems to use the same illumination factor. Therefore it is possible that some lines have been measured relative thicker. The measuring results show that there is no relation between the line width and the line direction. To show this dependence the standard deviation of the measurement should be smaller.

System	Zoom	d	σ	n
1	10x	44	6	9
	20x	26	6	9
	40x	20	3	9
2	5x	26	9	9
	10x	22	9	9
	20x	24	13	9
3	10x	76	14	9
	20x	74	7	9

Table 6. Line width at photo scale for different systems and zoom settdings. n = number of lines; d = line width in microns; σ = standard deviation of line width measurement (microns).

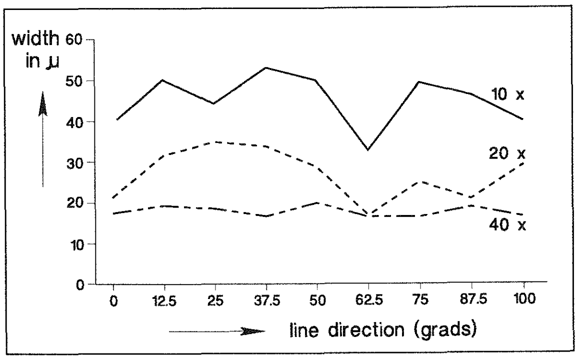

Figure 6. The line width of system 1 for different zoom settings.

4. CONCLUSIONS AND RECOMMENDATIONS

1. The superimposition accuracy at the position of the measuring mark through the whole stereomodel for the three tested systems varies from 9 to 28 micron at photo scale (table 3).
   If corrections are applied for systematic deviations then the accuracy varies from 5 to 22 micron.
2. Superimposition through the whole field of vieuw shows large systematic deviations (fig. 4). If these systematic deviations can be removed by system calibration then the accuracy for the three systems varies for magnification factor 10 from 10 to 24 micron at photo scale (table 5).
3. The width of the superimposed lines for different zoom settings is presented in table 6. For the systems 2 and 3 the line width is constant and is respectively 24 and 75 micron at photo scale. For system 1 the line width decreases from 44 to 20 microns when zooming in from 10 to 40 times.
4. The results of the research show that error detection of feature coordinates with superimposition is possible in a limited way.
   If the superimposition accuracy varies from 20 to 40 micron in the photo than this accuracy is two to three times worse than the photogrammetric measuring accuracy of points which describe hard topography. One must keep in mind too that when using mono-superimposition the detection of errors is difficult if errors are present in the Z-coordinates of the data base. These Z-coördinate errors are presented in the photo as x- and y shifts.
   In order to detect Z-coordinate errors stereo-superimposition is necessary. Through the high requirements of resolution, frequency and image synchronisation however, stereo-superimposition requires much more processor- and memory capacity, which is also reflected in the price.
5. A supplementary solution for the detection of errors which are present in the database could be to use the 'move to' routine of the analytical plotter. When the operator does not trust a certain object (because f.e the superposition is not optimal) then he can check these points with this routine. The 'move to' accuracy lies between 3 to 10 microns at photoscale. When using the 'move to' routine with only X, Y data base coordinates the operator himself has then to set the measuring mark on the terrain.
6. It is recommended to calibrate the superimposition systems if the purpose is to use them for the detection of large database errors. This has been shown by the results as presented in paragraph 3.3.

5. LITERATURE

1. Persie, M. van, Superimpositie. Beschrijving, precisie toepassingen. Afstudeerscriptie, Faculteit der Geodesie, TU Delft, februari 1991.
2. Witmer, R.C.J., Beeldinspiegeling: een hulpmiddel in de fotogrammetrie. NGT Geodesia 1991-7/8.
3. Bonjour, J.D., Eital, G. Köbl, O., 1988, Experiences with the Wild System-AP and its Stereo Injection Verification System, Proceedings ISPRS, Commission V, Kyoto.