STATE-OF-THE-ART TRENDS IN MAPPING – PAST, PRESENT AND FUTURE

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ABSTRACT

The photogrammetry has used the general development of the technique for its own purpose. It started with the analogue, continued with the analytical and reached now the digital methods. Digital systems do now allow a high degree of automation. With the digital possibilities in imaging and processing together with automation, we are not far away from on-line generation of ortho images. The integration with Geo Information Systems (GIS) leads now to an integrated information system – we do have a transition of mapping to Geoinformatics. The automatic feature extraction is under research and development; the first steps are not far away from operational use.

Parallel to the development of the data acquisition, the imaging technique has been changed. The film cameras have reached the end of the development with optimal optics, the introduction of image motion compensation and the use of gyro stabilized platforms. Now we are at the beginning of the change to digital imaging with the new cameras DMC and ADS40. Parallel to this we do have with the Synthetic Aperture Radar (SAR) new possibilities of mapping independent upon weather conditions. The direct determination of DEM's with laser scanning, named also LIDAR, and Interferometric SAR (IfSAR) has opened a new field like also the satellite imaging. With the very high-resolution satellite systems we are now in a competition to aerial photogrammetry.

1. INTRODUCTION

Mapping today is a data acquisition for a GIS; nevertheless the traditional expression of mapping is used. The information contents of maps is corresponding to a map scale – this relation we do have also in a GIS. The information contents and the accuracy of a GIS is corresponding to a representation scale. Of course such a scale is not very precise – there is only a very small difference between a GIS for a scale 1:40 000 and 1:50 000.

This paper deals only with topographic mapping; the close range photogrammetry with its high number of different applications is not respected.

An optimal planing of the environment for a sustainable development requires actual information about an area represented in a map (GIS). Today maps of most parts of the world are existing, very often also with the required scale. But maps have to be actual, that means complete in relation to the specified scale, geometric and thematic accurate. This is only possible with a permant update. Printed maps have to be updated in specified time interval depending upon the changes in the region - in urban areas in a shorter time interval than the rural areas. A GIS can be updated permanently, which means, important objects like roads can be included if they are build up, other objects have to be checked from time to time. The map update is the mayor problem, in several parts of the world no or not sufficient update programs are existing. If the changes are very large, it may be more economic to generate a completely new map instead of updating an old. During update, the quality standard, especially for the geometric accuracy, should be respected. An update by rubber sheating (just fitting new elements in relation to the neighbourhood) should be avoided, it leads to a continuous degrading of the map. Modern mapping is a GIS delivering the frame for other specific information. If the frame does not have the sufficient accuracy, it cannot fullfill the basic function. Today very often additional information will be added into a GIS based on GPS-survey and not by information in relation to the neighbourhood. This is only possible with a sufficient geometric absolute accuracy.

Mapping by photogrammetry has an old tradition. It started shortly after the invention of photographs, but became a standard application with the progress of the aircraft's and the analogue photogrammetric instruments after the First World War. Only by means of photogrammetry a mapping of a high percentage of the world was possible. With the presence of computers, the analogue methods have been replaced by analytical photogrammetry starting in the seventies. It took 20 to 30 years up the next change - towards digital photogrammetry, which became possible with faster and low expensive computers and sufficient storage space for digital images. Together with this development the degree of automation was growing, starting with computer supported pointing on analytical plotters, the use of CCD-cameras for automatic image matching in connection with analytical plotters, towards the full automatic image matching for the generation of digital elevation models (DEM's) and automatic aerial triangulation based on stored digital images. The first steps of automatic feature extraction have been made – this field is now a major field of research and development.

The classic photogrammetry is based on analogue photos. They are still dominating the aerial photogrammetry, but not anymore the close range application. In close range smaller images have been used and so the limited size of the CCD-arrays could be accepted. For aerial application now the first steps with 3-line-scanner and with a combination of large CCD's have been made. A quite different solution is the direct data acquisition by laser scanning. In some survey administrations of Germany, the laser scanning has replaced the photogrammetric determination of terrain heights. Even based on photogrammetry, the direct measurement of contour lines has been nearly totally replaced by point raster, partially supplemented by break and contour lines. This fits better to the requirement of digital height models, which are required for GIS-applications and ortho images. Up to now SAR is used only for special applications. The high price and the limited information contents is reducing the progress of this technique, but in near future also high resolution space borne SAR-systems with 1m resolution will come for civilian applications and this can change the situation. With IfSAR a world wide DEM will be created based on the SRTM-mission. Differential IfSAR is also able to give precise information about the change of the topographic surface caused by earthquakes, tectonic movements and mining activities.

2. ANALOGUE PHOTOGRAMMETRY

Mapping in the scale 1 : 25 000 started in Germany in the 19th century by plane tabling. It took approximately 100 years to finish the first basic survey. Such a time intensive fieldwork, which took not care for map updating, is not possible anymore. A solution was found by photogrammetry, which can reduce the required fieldwork to a minimum and can cover also areas with difficult access. The first geometric exact reconstruction of the imaged objects has been based on the measurement of image coordinates and parallaxes by stereo comparators and the computation of the object coordinates. Without computer this was very time consuming and not a solution for mapping large areas. The general acceptance of photogrammetry for mapping required the progress of the airplanes, aerial mapping cameras and analogue photogrammetric instruments (analogue stereo plotters). Together with the hardware components, also the required techniques, like relative and absolute orientation and strip adjustment have been developed. The product was a drawn line map, where the height was presented by directly measured contour lines and additional spot points. Also with the analogue technique it was possible to generate orthoimages by storing manual measured height profiles by engraving on coated glass plates. There was a continuous development from the analogue to the analytical technique, starting with the registration of model and image coordinates.

3. ANALYTICAL PHOTOGRAMMETRY

The acceptance of analytical photogrammetry required a sufficient computer technique. So it took nearly 20 years from the development of the first analytical plotter by Helava in 1957 to a more wide application. It was not a rapid change; analogue instruments had been in use for longer time parallel to analytic stereo plotters, mainly caused by the required high investment. With the analytical photogrammetry, the first possibilities of an automatic operator support was given, but it took longer time for the realisation of the new possibilities. The first analytical plotters have used the technique developed for analogue instruments, just transformed to the new instruments. So even today on digital stereo plotters the relative and absolute orientation survived and have not been totally replaced by bundle orientation. It took also longer time to replace the block adjustment by independent models, developed for analogue instruments, by the more precise and flexible bundle block adjustment.

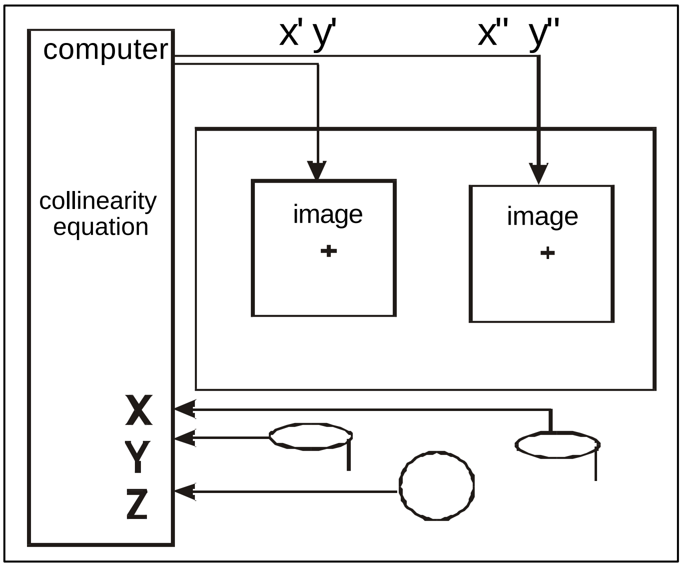

Figure 1: principal of analytical plotter (model mode)

From the beginning the relative and absolute orientation have been done by adjustment, speeding up the orientation process and allowing a better accuracy. Only the inner orientation is required for images, which shall be used later again, and it is possible to use the exterior orientation determined by bundle block adjustment. There is no limitation of the focal length like in analogue plotters, so also close range photos, even in convergent arrangement can be used. The internal loop for changing the object coordinates into image positions is usually based on the collinearity equation, but this can be improved by any type of correction like lens distortion or systematic image errors. The mathematical model can also be replaced or improved by others for handling images with a special geometry like panoramic or satellite line scanner images.

The first analytical plotters have been equipped with plotting tables, but the direct plotting has been replaced soon by storing the plot information and displaying it on a screen with the possibility of editing. This was the first step for the introduction of a GIS. Also the time consuming direct measurement of contour lines, requiring well-trained operators, has been changed after short time to the more precise measurement of a point grid. This invention of digital elevation models has been used also for other purposes. The DEM's did not only allow the more fast computation of contour lines, also any type of volume calculation, graphic presentation and the generation of cross sections was possible, opened new applications. The measurement of point grids could be optimised by progressive sampling – a first measurement of a wide grid followed by additional computer supported approximate pointing in the areas with stronger curvature, where a higher point density was required for the precise description of the 3D-surface.

It was also possible to optimise the data acquisition for block adjustment. The position of a tie point in one image could be transferred to the approximate position in other images. By this method also blocks with higher image overlap have been measured very fast. For example the subsidence in coal mining areas has been determined by bundle block adjustment using blocks with 60% sidelap and some additional crossing flight lines. The data acquisition for such blocks required not much more time like standard blocks, but allowed a good reliability and an object point accuracy in the range of +/- 2cm up to +/-3cm.

The transition from analytical to digital photogrammetry started with CCD-cameras connected with analytical plotters, like the Kern DSR, or with special devices, like the Rollei Reseau Scanner. With the CCD-cameras attached to the Kern DSR an image correlation was possible, but it was not faster like the human operator, so it was used mainly for research and not so much for production. The Rollei Reseau Scanner connected a simple mechanical device with the high accuracy of a reseau platen and a CCD-camera, enabling automatic point detection.

4. DIGITAL PHOTOGRAMMETRY

The higher flexibility of analytic against analogue photogrammetry has been further improved by the introduction of digital photogrammetry. From the first prototypes with limited viewing and image movement possibilities, it took only approximate 10 years up to the wide spread use. Digital images are required; in the beginning only digital space and close range images have been available, so analogue photos have to be digitised – that means scanned. The firstly available drum scanner have been limited to an accuracy of approximately 25µm, this was also the case for flat bed scanners developed for scanning maps. In addition the resolution of these scanners yielded to a loss of information. Aerial photogrammetric images do have a resolution of approximately 40lp/mm up to 60lp/mm. The relation between a line pair (lp) and the pixel size under operational conditions can be simplified to: 1 line pair = 2 pixels. 40lp/mm are corresponding to 80pixel/mm or a pixel size of 12µm or 60lp/mm → 8µm pixel size. Expressed in dots per inch (dpi), 12µm pixel size are corresponding to 2000 dpi or 8µm pixel size = 3000 dpi. Today cheap desktop scanners with such a nominal resolution are available, but they do not have really such a quality; at first the physical pixel size is larger than the nominal, the optics are not sufficient and the geometric accuracy is usually limited to ~ 50µm. A geometric calibration is not possible, the CCD-lines are not moving in a reproducing manner. So the especially developed photogrammetric image scanners are required. The first photogrammetric image scanners have been limited to a grey value resolution of 8bit = 256 different grey values. This is more than required for the human eye, but the human eye can adapt to the local brightness and sees more details like 8bit with constant setting over the whole image. With 8bit grey values there is a loss of information in shadows and/or bright parts. By this reason, the more new photogrammetric scanners do have a grey value resolution of 12 bit (4096 grey values). The achieved images can be reduced later to a grey value resolution of 8bit by local adaptation (local histogram manipulation) for saving disk space.

A black and white standard size aerial image with 12µm pixel size and 8bit resolution requires 368 Mb storage space, a colour image 1.1 Gb. This is leading to a high amount of data even for not so large blocks, but today this problem can be handled. In addition the storing capacities are growing every year. There is still a bottleneck with the data transfer, which may be time consuming. The amount of data can be reduced by image compression. Well known is JPEG, but it is based on a grouping of the pixels into sub-areas, causing small grey value discontinuities at the limits of the sub-areas. This is not disturbing the human operator, but it may have a negative influence to an automatic image matching. Better results have been achieved with image compression by wavelet.

The basic principle of a digital stereo workstation is the same like for the analytical plotter (figure 1). Instead of moving the photos on the photo carrier, the images have to be moved on the screen. The digital plotters started with a movement of the images step by step and a movement of the floating mark in the center part of the sub-area; today with faster computers, usually the floating mark is fixed and the images are scrolled continuously. For a stereoscopic impression, each eye has to see only the corresponding image, requiring an image separation. The simplest method of image separation is the use of the anaglyphic mode (red and green image with green and red eye filters). It is limited to black and white images. For colour images mainly two methods are used, the Crystal Eye method and polarisation. In both cases the left and right images are shown, one after the other with a period of 50Hz. The Crystal Eye method is based on crystal shutters in form of spectacles. Synchronised by infrared light, one glass of the spectacle is opaque and the other transparent, so the left eye can see only the left image 50 times per second and the right eye can see only the right image. In the case of polarisation, there is a polarisation filter in front of the screen, changing the polarisation direction from horizontal to vertical with a period of 50Hz, synchronised with the change of the images on the screen. This has to be viewed through spectacles with polarisation filters – one with horizontal and the other with vertical polarisation. The Crystal Eye method has the advantage that it is available also for very large screens, for standard size screens the polarisation has some advantages – the spectacles are not so heavy and cheap. All methods can be used for a small group of persons viewing together to the stereo model.

Analytical plotters are still expensive instruments, the accuracy of the photo carriers and the quality of the optics do have a basic price, which is not negligible. This is different for the digital photogrammetry; the geometric problem is solved with the digital images (by scanning or directly digital imaging). With digital images no loss of accuracy is possible, the geometry is fixed by the pixel address. For digital photogrammetric stereo workstations mainly a PC and if not the anaglyphic mode shall be used, in addition an image separation device is required. Today high level standard PC's are sufficient. On this low financial base a much more wide range of digital stereo workstations exists. The price is mainly depending upon the software. Several problems can be solved also with simple workstations and not in any case a stereo workstation is required. Based on a DEM orthoimages can be created and they can be used for a geometric correct mono-plotting.

The digital photogrammetry has the advantage of possible automation. Of course no digital photogrammetric workstation is required for this, several processes can be made off-line, but the digital stereo plotter has the advantage of a visual data check. If scanned photos are used, the automation starts with the inner orientation– the fiducial marks do have a limited number of different shapes, so the center can be identified. The standard method for the determination of the exterior orientation is still the bundle block adjustment. The time consuming manual measurement of tie points can be done by automatic aerial triangulation. It requires only the manual measurement of control points – they do have a too different shape which does not allow an automation with the exception of well defined targeted points. Automatic aerotriangulation is the data acquisition of tie points, but nevertheless very often it is used together with a bundle block adjustment for blunder identification. The automatic aerotriangulation has become a standard procedure, but it has some limitations in forest and mountainous areas. Here it has to be supplemented by manual measurements. In general this method has replaced the artificial point marking which was also during the analytical phase not justified because of it's loss of accuracy.

By automatic image matching DEM's can be generated. The used methods are mainly different in generating the approximate positions of corresponding points and the type of final matching. A higher number of programs are based on image pyramids – for the reduction of the problem of initial relation of one image to the other and in relation to the three-dimensional ground. The images are reduced in the size and after getting the relations, it will be improved step by step to the pyramids with higher image resolution. The initial relation may be feature or area based. In the case of feature based matching, well-defined corners are identified by different operators and the pattern of corresponding points in both images are compared. In general the identification of corresponding points (= homologue points) can be simplified if the exterior orientation and the image geometry is known. Corresponding points are located on the epipolar plane, intersecting the images with the epipolar lines. So the homologue points only have to be searched in one direction. Totally independent upon information about the exterior orientation and the image geometry, the region growing method is operating. Starting from few corresponding points, which may come from the data acquisition for bundle adjustment, directly in the original images neighboured points are identified in any direction.

Based on the approximate position, the position of the homologue points may be identified by the correlation coefficient, an expression for the correspondence of small image matrixes in both images. A reference matrix of one image will be compared with a little larger search matrix of the other. For all possible combinations of the reference matrix with the search matrix, the correlation coefficient will be computed. If there is a clear maximum with a correlation coefficient exceeding a chosen threshold, this corresponds to the position of homologue points. The difference in size between reference and search matrix must be sufficient for fitting discrepancies of the approximate positions, but not too large to avoid a second maximum in the case of repeating objects. The correlation coefficient is the relation of the covariance to the standard deviation of the grey values of both images in the sub-matrixes, that means it is independent upon the level and range of the grey values – so a preceding change of the contrast and level of the grey values has no influence. The correlation coefficient is comparing sub-matrixes of the same size, this is only correct for images in the normal case and a horizontal area. It is only an approximation if the view direction is not vertical and/or the ground is tilted. This problem can be solved by the least squares matching taking care about a tilt by affine transformation of the sub-matrixes and a linear change of the grey values. The least squares matching has only a small radius of convergence, by this reason usually a preceding image correlation will be calculated.

Similar functions like for the automatic image matching are used for the automatic aerial triangulation, but it is more dominated by feature extraction.

The automatic image matching has reached a high level of accuracy for the matched ground points; it corresponds to the accuracy of a human operator. The problem are the selected points. A human operator, measuring a grid of height points, is setting down the floating mark to the ground, even if the floating mark will be on top of a building. An automatic image matching will generate not a DEM; it will generate a digital surface model with points located on top of the visual objects. A similar problem we do have with laser scanning and IfSAR.

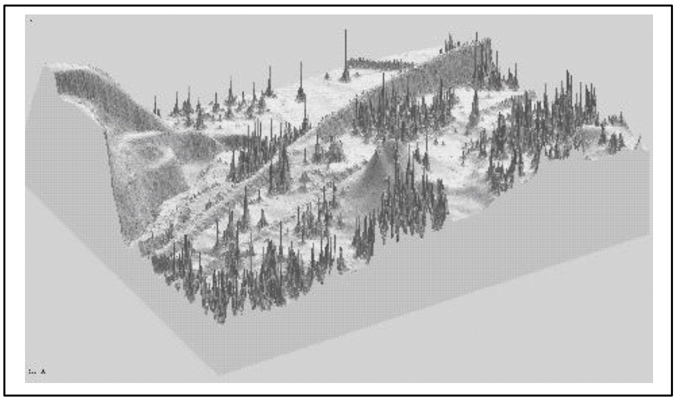

Figure 2: DSM generated by laser scanning

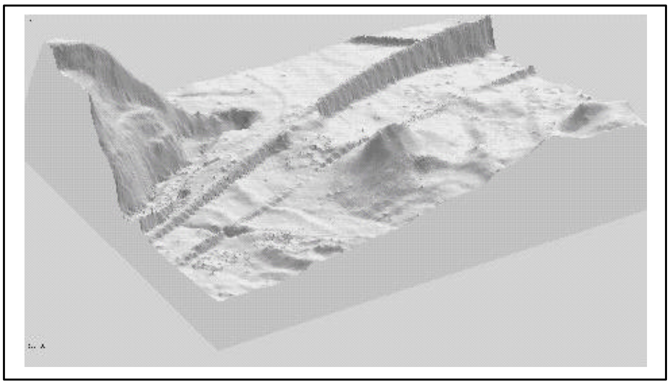

Figure 3: DSM automatically reduced to a DEM

Figure 2 shows the result of a DSM generated by laser scanning. The results of automatic image matching are similar. The manual editing of such a DSM for the generation of a DEM, describing only the bare surface without influence of the vegetation and buildings is very time consuming and not an economic solution. By an analysis of the surface, such elements can be identified automatically like shown in figure 3 (Hannover program RASCOR) (Passini 2002).

The manual generation and updating of line maps is very time consuming, especially if it is done in the stereoscopic mode. A shift of the image interpretation to the user can be done by the generation of orthoimages, based on automatically generated or always existing DEM's. Orthoimages do have the geometry of maps and the original contents of images. This is the fastest procedure of generating geo-products. Orthoimages do have the advantage of containing the whole available information without reduction to the information included in the maps but also the disadvantage of non-interpretation. In several countries orthoimages became an equal ranking product as supplement to line maps. In addition, orthoimages are used as fast information generated at the mid time of the updating of line maps. For the creation of new ownership cadastral systems today orthoimages are dominating.

Another possibility of speeding up the generation and updating of line maps is the automatic cartographic feature extraction. This is just now a major field of research and development with the first applications not far away of being operational. The identification and interpretation of objects in images is a complicate task requiring a trained operator. By this reason only the first steps have been made automatically. Objects are identified based on the relation to the neighbourhood. The identification of edges is simple, it can be done by standard operators, but the interpretation what type of line it is, is a difficult task. It is quite depending upon the image scale and the landscape. A line in rural areas for example may be just a separation of fields; it may be a road or a railroad. For the correct identification a longer distance has to be taken into care. If the line continues over longer distance, it may not be a field separation. Buildings on the side and crossings may support the separation between road and railroad, but a very large range has to be respected. In addition a line may be partially hidden by trees or other objects and disturbed by shadows like shown in figure 4.

Figure 4: road partially hidden by trees (IKONOS, 1m pixel size)

These problems can only be solved with sufficient information about the object to be analyzed. An optimal method is the knowledge-based system. Based on some information always available, like for example in the German Topographic-Cartographic Information System ATKIS, the required information about the to be selected objects can be improved and used for other corresponding objects.

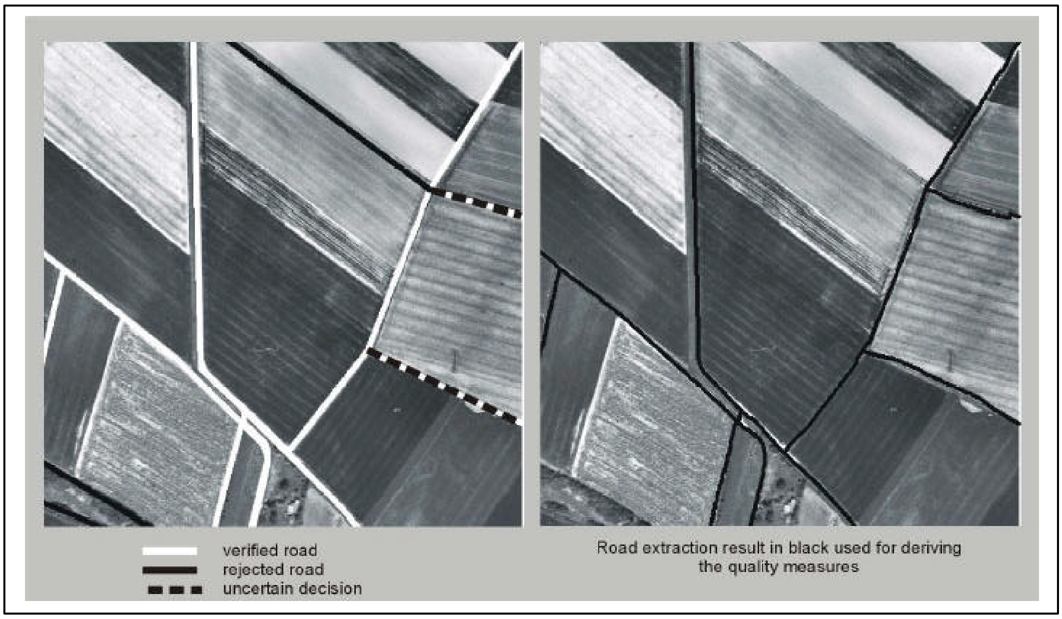

Figure 5: result of a fully automatic quality control of the verification step as it is transferred to the interactive quality control by an operator (Busch, Willrich 2002)

A typical example for the possibilities of knowledge based feature extraction can be seen in figure 5, a result of a development project of the University of Hannover and the German Federal Agency for Cartography and Geodesy. For the verification of the ATKIS data in digital orthoimages roads are extracted automatically and compared with the available information in ATKIS. The operator will see the result on the screen with the information if the system has verified or rejected some roads or if it is an uncertain decision. The operator can confirm or reject the individual results. Such a type of operator supported feature extraction is not far away from operational use. In the near future only automated systems with operator support seems to be an economic solution.

5. DIRECT GEOREFERENCING

The exterior orientation can directly be determined by a combination of relative kinematic GPS-positioning and an inertial measurement unit (IMU). An IMU is the basic component of an inertial navigation system (INS), but in photogrammetry it is not used for navigation, only for the determination of the exterior orientation. An IMU includes gyros for the determination of the 3 rotations roll, pitch and yaw and 3 accelerometer, which enables by a double integration of the acceleration the computation of coordinate differences. The tendency goes to the use of fiber optic gyros instead of rotating gyros. By theory the IMU is sufficient for the computation of the exterior orientation, but it has a poor error propagation and only the short time accuracy is sufficient. So the IMU has to be integrated with GPS-positioning, which can guarantee the absolute accuracy with a lower frequency. By iterative Kalman filtering, the IMU- and the GPS-positioning are integrated to a full sensor orientation. The quality of the exterior orientation determined by the combination of GPS and IMU has reached a level, sufficient for several applications. Of course such a system has to be calibrated over a test field. A ground point accuracy up to the range of 10cm to 20cm for all coordinate components can be reached. There are still some remaining limitations – the model set up for a stereo compilation shows larger y-parallaxes which have to be solved by an integrated sensor orientation, a bundle block adjustment using in addition tie points which may be generated by automatic aerotriangulation.

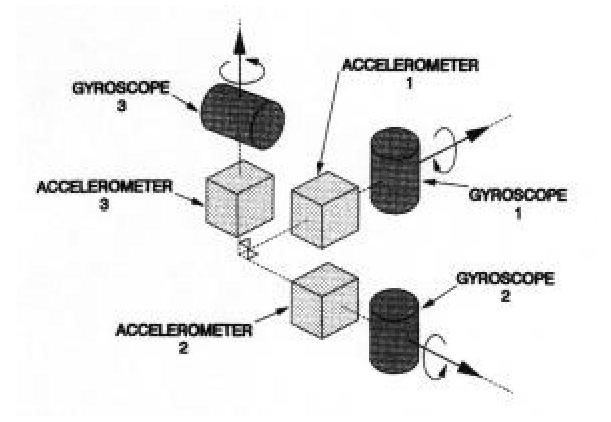

Figure 6: basic principle of an IMU

6. DIGITAL CAMERAS

Up to now photo flights are based on analogue film cameras and the film will be scanned. A standard aerial photo with 40lp/mm corresponds to 18400 x 18400 pixel. There are no CCD-chips with such a number of pixels available. Some commercial applications are using CCD-cameras with up to 4000 x 4000 pixels, but such images are not corresponding to the information contents of the classical film cameras.

Leica Geosystems has developed in co-operation with the German Aerospace Center DLR a three-line-scanner ADS40, viewing with the panchromatic lines 28° forward, to the nadir and 14° backward. By this combination each object point is imaged 3 times with a stereo angle up to 42°. Each panchromatic view direction includes 2 CCD-lines, each with 12000 pixels in staggered arrangement, leading to 24 000 pixels, or from a flying altitude of 3000m a swath of 3.75km is covered with 15cm ground pixel size. Of course such a system must be combined with direct sensor orientation. For the handling of stereo models an improvement of the orientation by integrated sensor orientation is available.

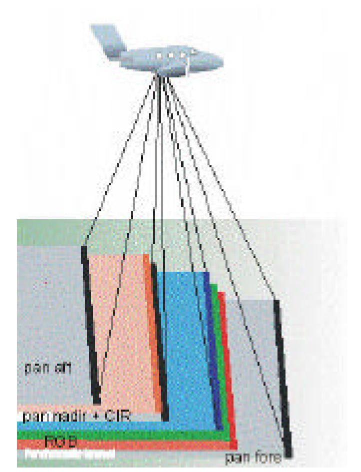

Figure 7: principle ADS40

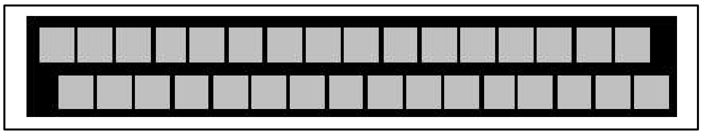

Figure 8: staggered CCD-lines

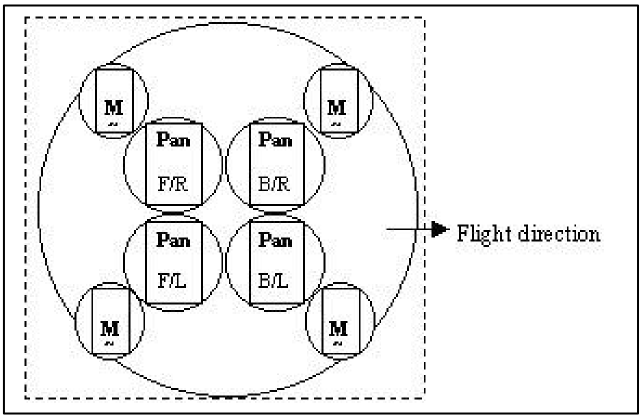

Figure 9: DMC standard constellation with four panchromatic (Pan) and 4 multi-spectral (M) modules, where

F/R = forward right looking (facing flight direction)
B/R = backward right looking
F/L = forward left looking
B/L = backward left looking.
M = color camera

Z/I-Imaging has chosen a different solution; it is using with the Digital Metric Camera DMC a combination of 4 CCD's, each with 4096 x 7168 pixel. The resulting digital image with approximately 8000 x 14 000 pixels with a pixel size of 12µm x 12µm and a focal length of 120mm is generation a field of view in flight direction of 43.1° and across flight direction 75.4°. A bundle block adjustment of a small block with crossing flight directions with an image scale 1 : 12 800 (flying height 1500m) was resulting in a sigma0 of 2µm (1/6 pixel) and at independent check points in SX=SY=+/-4cm corresponding to 3.3µm in the image (1/4 pixel) and SZ=+/-10cm corresponding to 2.7µm x-parallax (Doerstel et al 2002). Such a high accuracy cannot be reached with a film camera. Even with the smaller number of pixels compared to a standard aerial camera, the accuracy potential is higher.

The well-defined color bands of digital cameras are improving the possibilities of object classification. With the overlapping spectral range of traditional aerial color photos a classification was not successful.

7. LASER SCANNING

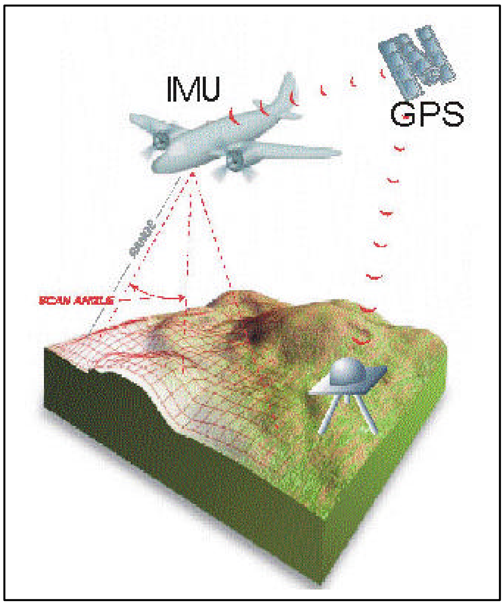

Figure 10: principle of laser scanning

By laser scanning, also named as LIDAR, the distances and directions from the sensor in the aircraft to the ground are determined. Based on the direct sensor orientation, the ground coordinates can be determined. The laser beam is widened by the optics to avoid a too small spot. If the ray hits a tree, a first reflection (first pulse) will come back earlier like the last reflection (last pulse), but the last pulse will not be in any case on the ground. A DSM will be generated and has to be reduced to a DEM. The high density of points makes the reduction of the DSM to a DEM easier. The accuracy of the ground points is in the range of SZ=+/-10cm up to 20cm. The tendency of laser scanning goes to the generation of an additional grey value image based on the reflected intensity. Such an image is simplifying the calibration and can be used also for supporting the generation of a DEM. Some federal survey administrations in Germany have switched totally from the generation of DEM's with standard photogrammetric methods to laser scanning. In open areas the standard photogrammetry is more economic, but for the more precise determination of DEM's in Germany there are mainly forest areas left and here laser scanning is more economic under the conditions of Germany.

8. RADAR IMAGING

Optical images are requiring very good weather conditions, which are not often available in some areas. An alternative solution is the generation of Synthetic Aperture Radar (SAR) images. Radar is independent upon weather and light conditions. The geometry of SAR-images is quite different from perspective optical images causing problems in mountainous areas and in cities. The resolution cannot be compared with optical images, the information contents of a SAR-image corresponds to an optical image with 3 to 5 times larger pixel size.

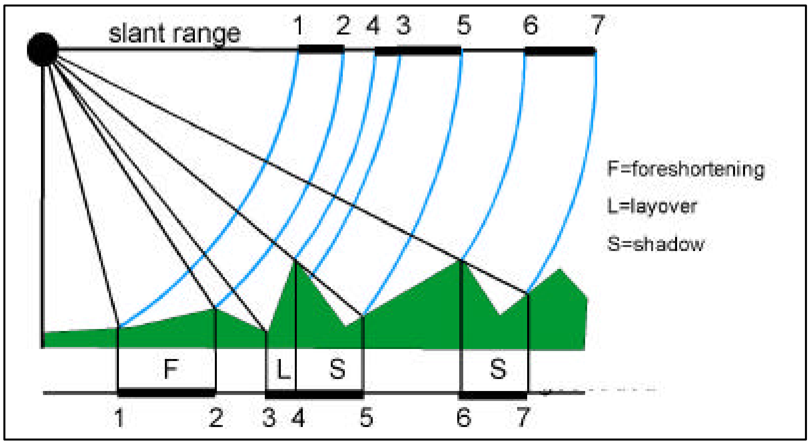

Figure 11: geometry and geometric problems of a SAR-image

The geometric problems in mountainous areas are obvious in figure 11. The top of a mountain may be located in front of the foot of the mountain (layover). Such a problem cannot be solved by the generation of an orthoimage based on a DEM.

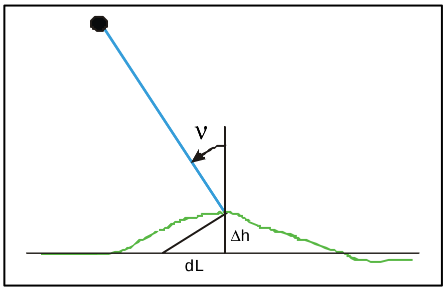

Figure 12: Dislocation dL of a point in a SAR-image depending upon a discrepancy in Z (Δh) and the incidence angle ν

$$dL = \frac{dh}{\tan \nu}$$

The influence of height discrepancies to the location in SAR-images is exceeding usually the influence in optical images. In optical images we do have the relation: $dL = dh \bullet \tan \nu$. The incidence angle (local nadir angle of the imaging direction) usually is below 45° enlarging the differences in Z as horizontal displacement.

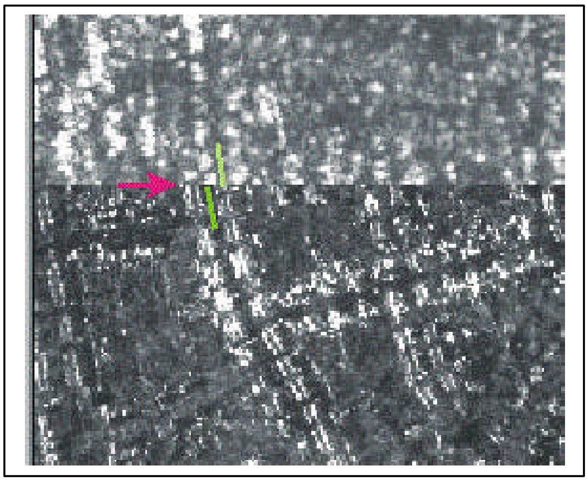

Figure 13: geocoded airborne SAR-images,
upper part: P-band (2.5m pixel) imaged from right hand side
lower part: X-band (1m pixel) imaged from left hand side

Figure 13 shows the effect of the displacement of buildings in a combination of SAR-orthoimages. It looks like a shift of the road, but the road is just presented by the combination of buildings along the road.

The interpretation of SAR-images is more difficult like the interpretation of optical images; mainly the effect of the height variation is generating gray values in addition to mirror effects generating dark water surfaces.

High resolution airborne SAR-images are expensive. The now for civilian applications available spaceborne images do not have a resolution sufficient for mapping, but this will change in the near future. In 2005 the German TerraSAR-X with 1m pixel size shall be launched.

Important for the generation of DEM's is the airborne or spaceborne interferometric SAR (IfSAR). It includes one broadcasting antenna and 2 receiving antennas. The phase difference between the received information of both antennas can be used for the determination of a DEM. A nearly worldwide DEM will be generated based on the Shuttle Radar Topographic Mission. With the German X-band, which will not lead to a complete coverage, a relative Z-accuracy of 3m and an absolute Z-accuracy of 6m has been reached. With the US C-band a good coverage will be reached, but the availability is not clear.

With differential IfSAR, a combination of IfSAR-data with a time interval, surface elevation changes caused for example by earthquakes, general tectonic movements, subsidence in mining areas and volcanic activities can be determined with high precision. The relative accuracy can be in the range of one cm, but larger changes may cause some ambiguity problems.

CONCLUSION AND PERSPECTIVE TO FURTHER DEVELOPMENTS

Mapping today is a data acquisition for GeoInformation systems. In several countries we always do have a topographic-cartographic information system or it is under development. In a shorter time period this will become the general standard. They will include also digital elevation models, which have to be generated with a sufficient accuracy if they do not exist. Orthoimages are one layer of such a GIS.

There is a clear trend to digital photogrammetry. Digital photogrammetric stereo workstations have replaced very fast most of the other - this will continue. Opposite to analytical plotters, having a fixed minimal price on a higher level, the basis price of digital plotters is mainly determined by a PC and the stereo viewing device and there is a wide range of software products starting on a lower level with limited possibilities up to the highest level. Digital airborne cameras came just into operational status; over longer period they will replace the film-based cameras. The DMC can be used with the existing software of digital plotters and includes the possibility also for high precision, while the ADS40 needs a special software and is depending upon the quality of direct georeferencing. The direct georeferencing will be used very soon for a higher percentage of the traditional photo flights.

The generation of digital elevation models is possible with quite different methods. For higher precision, laser scanning will become dominating, for the medium accuracy range, automatic image matching will be used and for the lower accuracy range and wide areas IfSAR will come more and more. The use of the different methods will overlap depending upon the local conditions. In any case, the reduction of the derived digital surface models to DEM's will be done automatically.

The competition between airborne and spaceborne methods will grow. The selection of the methods will be done by economic reasons but also by the more traditional reasons of classification. If classified aerial images do not include more details like unclassified space images, there is no more reason for a classification. The number of very high-resolution space systems is growing and we do have always a competition leading to price reductions in some areas.

Civilian available radar images will have very soon a better resolution and can be used for special applications. Just now we do have a high price level, but this will be reduced by spaceborne sensors.

In general the different methods, from traditional photogrammetry over laser scanner to SAR and IfSAR will be used together and with overlapping applications.

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