

HISTORICAL AERIAL PHOTOGRAPHS AND DIGITAL PHOTOGRAMMETRY FOR IMPACT ANALYSES ON DERELICT LAND SITES IN HUMAN SETTLEMENT AREAS

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ABSTRACT:

In old industrialized areas large sites of former coal and steel industries offer a great potential for internal urban development. The reuse of such derelict and mostly contaminated land requires systematic research to identify possible risks for human health and the environment. Hence a historic site investigation needs to be carried out to find possible sources of pollutants in a sites history. Besides others sources of information historical aerial photographs represent a valuable documentation about former site development. Using the example of the Ruhr District in North Rhine-Westphalia (Germany) this paper discusses the potential of digital photogrammetry for analysing historical aerial photographs as part of a historic research incorporating three-dimensional vision, direct digital mapping in stereo-models as well as the generation of elevation models.

1. INTRODUCTION

In densely populated areas the use of green-field contradicts planning objectives of local authorities and government aiming to protect remaining open space and the countryside. Therefore, the utilization of derelict and contaminated land in settlement areas is an important instrument of urban management.

Prior to the recycling of derelict and contaminated land former plant installations such as buildings, polluting spillage or contaminated landfills have to be disposed of. Hence, systematic research is necessary to identify possible risks for human health and the environment caused by hazardous substances in the ground. Due to the size of such sites area wide drawing of soil and groundwater samples is far too expensive; therefore selective sampling is required. To find contaminated areas where sampling should be executed a historic site investigation has to be performed. This implies to reconstruct the buildings and installations of the plant as well as the products, production processes and raw materials, etc. For this purpose, all relevant historic documents concerning the site development have to be examined for evidence on possible contaminants.

1.1 GIS

Possibly contaminated areas within the site have to be located and delineated. This implies the use of GIS for assembling, analysing and presenting all relevant information concerning the attributes and spatial properties of every single feature that existed on the site.

1.2 Types of data

From the GIS point of view, the available information can be differentiated as follows:

- *Archival records* such as texts, statistics, drawings, charts or photographs documenting processes, materials, buildings and installations in different stages of the site development from different points of view.
- *Geo-topographic information*
 - *maps or plans*, showing a schematic view of selected features at a given period,

◦ *aerial photographs*, giving an overview over the site, showing everything that could be seen from above at the moment of exposure.

Because of their historic origin, these sources usually are available only in an analogue format and have to be transformed into digital files for GIS integration.

1.2.1 Archival records: Material from archives usually does not have a direct spatial reference for use in GIS. But together with geo-topographic information it can be very valuable in supplementing spatially related information. Detailed descriptions regarding the development and documentations about different states of certain geo-objects as well as oblique views on those earth features can be helpful in reproduction of their history.

1.2.2 Maps and Plans: Maps and plans are easy to integrate into GIS. After scanning and rectifying the map relevant features are digitized and supplemented by attributes from map captions and complementary information drawn from archival records.

1.2.3 Aerial photographs: For aerial photographs data integration in GIS is more complex. On the one hand, simple rectification would not make it possible to fully use their semantic and geometric potential of three-dimensional vision. On the other hand, features cannot simply be identified since there is no explanatory legend like in maps. From aerial photographs features can only be extracted by interpretation. This implies identifying objects on the basis of their appearance in the image.

So far, in historic research on former industrialised sites aerial photographs have been analysed using mirror stereoscopes or multiscopes transferring objects from an image into a map. Then, these maps are transferred into a GIS and objects are captured by digitizing. Considering the geometric properties of aerial photographs it is obvious that this approach involves systematic and random geometric distortions caused by the camera geometry and uncontrolled platform movement. Furthermore, the manual transfer of objects from imagery to maps is another source of geometric mapping inaccuracies.

Better levels of accuracy can be achieved by employing softcopy photogrammetry for direct feature identification and mapping in a digital three-dimensional model. Softcopy photogrammetry also allows deriving surface models for the analysis of hazardous waste sites.

At first sight, it seems rather difficult, if not impossible to apply digital photogrammetry to historic aerial photography: For most of these photographs meta-information on inner orientation like focal length, coordinates of fiducial marks or distortion parameters is not available or at least inaccurate. In addition, specifications of the flight mission such as flying height or time of day are not easy to find or do not exist.

On the one hand the lack of metadata and limitations in geometric image quality in terms of photogrammetric requirements do imply not to use such imagery in softcopy photogrammetry. But on the other hand aerial photographs are the most impartial and detailed source of geo-information available. Therefore it is worth to put some effort into the preparation of historic imagery and the reconstruction of inevitable parameters for photogrammetric analysis.

2. PHOTOGRAMMETRIC ANALYSIS WITH HISTORICAL AERIAL PHOTOGRAPHS

In Germany two major types of historic aerial photography are available for conducting historical research:

- *Aerial survey imagery*, taken by mapping authorities or private contractors for the purpose of creation or continuation of base maps since the fifties of the last century.
- *Reconnaissance imagery*, recorded by the allied forces during World War II (WW II) from 1939 to 1945.

2.1 Aerial survey imagery

Photographs for surveying purposes as is generally known are taken using frame cameras. Photo flights are carried out under ideal weather conditions only, requiring no clouds, no but slight winds only and a time of day, when the disturbance of shadows is smallest. Frame cameras are equipped with fiducial marks and a data panel containing base data of the camera and the flight like date, time, altitude and mission number. They are calibrated at regular intervals and the corresponding calibration report provides the focal length of the lens, coordinates of fiducial marks and the principle point of autocollimation and mostly parameters of radial distortion. Most of these parameters are required for softcopy photogrammetry processing. Unfortunately often the calibration report is not available for elder aerial photographs. Occasionally it does not exist anymore and in other cases suppliers do not deliver calibration reports with the imagery. Sometimes calibration reports can be delivered subsequently by the original contractor, calibration institutes or the appropriate mapping authority. But the older the imagery the less is the opportunity of obtaining a calibration report with aerial photographs.

2.2 Reconnaissance imagery

Aerial images from reconnaissance missions in World War II were primarily aimed for optimal visual inspection and mostly lack the geometric determination of frame cameras. Therefore usable fiducial marks are rarely to identify in the photographs and calibration reports are not available with this imagery. Furthermore the conditions while taking these photographs were rather disadvantageous. They had to be recorded despite cloudy

weather and wind and from high and changing altitudes. Thus distortions and visual disturbances are present in the imagery (Figure 1).



Figure 1: Aerial photograph from reconnaissance mission on December 24, 1940 over Gelsenkirchen-Horst, Germany

Besides geometric restrictions due to the lack of inner orientation parameters and the absence of usable fiducial marks distortions from roll and pitch are quite usual to reconnaissance imagery. Furthermore the split vertical camera configuration was a very common kind of camera mounting. It consists of two slightly inclined cameras pointing beneath the plane at angles of $5 - 10^\circ$ (Figure 2). Consequently a wider ground track could be covered at once. But these images therefore contain distortions like from rolling of the plane (LUA 2006, p. 48).

The visual quality especially of reconnaissance imagery can be very poor. This is either caused by disturbing clouds in the field of vision or induced by bad conditions throughout tradition of the photographs. Some damage arises from improper conditions during transport or storage like high humidity or extreme changes in temperature. Other deficiencies are caused by accidental exposure to light or disturbances during the processing of original films or hardcopies in field laboratories (Stanley, Leaf, Babington Smith). Likewise a great part of today's available negative film is just a copy of former hardcopies which were drawn from original films. Hence even more geometric and radiometric errors are likely to be inherent to this imagery.

In North Rhine-Westphalia there are about 300,000 aerial photographs available from American and British forces reconnaissance flights. They are catalogued in a database containing metadata derived from original plots created shortly after acquisition of the imagery. These plots show footprints of each picture or at least the ground coverage of a flight track in base maps of the recorded area. In addition every plot contains an information box with general flight parameters like date, time, flying height, focal length etc..

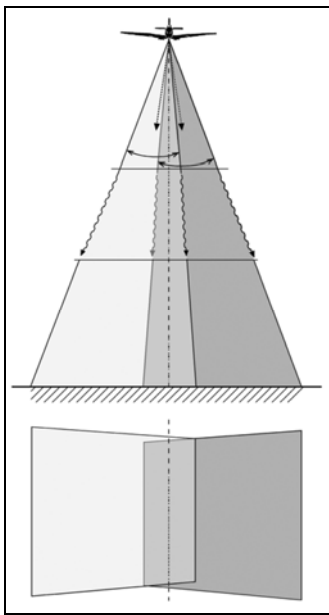


Figure 2: Split Vertical-configuration (LUA 2006, p. 50)

As stated above a considerable number of aerial photography is available for historical research at least since WW II. However most of this imagery does not immediately meet the requirements of softcopy photogrammetry in terms of geometric accuracy and available parameters for inner orientation. Therefore they need pre-processing to enable them for analysis using digital photogrammetry.

2.3 Preparation of historical aerial photographs for utilization in digital photogrammetry

Generally geometric deficiencies in imagery as well as missing parameters on inner orientation are in contradiction to the demands of photogrammetric analysis. But since aerial photographs are the most objective and sometimes the only source of historical spatial information, spending some effort on preparing such images for softcopy photogrammetry appears to be worthwhile. That is

- digitizing respectively scanning of the hardcopy images,
- enhancing the visual (radiometric) quality of the images and
- determining and validating possible parameters of inner orientation.

2.3.1 Digitizing of historical aerial photography: Scanning is the key to digital analysis for analogue imagery. Details that get lost at this stage of image processing can not be recovered afterwards (Baltsavias 1998, p. 44). Therefore scanning hardware and parameter settings have to be chosen very carefully.

A photogrammetric scanner is certainly the preferred scanning hardware for this purpose. But considering the poor geometry of the historical photographs high end desktop scanners can be an adequate choice as well (Kasser 2002, p. 63). To preserve as many details as possible from the imagery, scanning at resolutions of 1200dpi geometrically and 16 bit radiometrically is recommended. For better data handling within image

enhancement, the radiometric resolution can be reduced to 8 bit subsequently.

2.3.2 Radiometric image enhancement: After scanning image contrast appears weakened and edges seem to be softened. These effects can be equalised by contrast stretch and sharpening filters. These tools are available in specialised remote sensing software as well as in common image processing applications. Image enhancement has to be applied with great caution because mistakes might eliminate details from the imagery irretrievably. After contrast stretch, the radiometric depth can be reduced to 8 bit.

Especially reconnaissance imagery comprises different limitations in visual interpretability and need image enhancement prior to photogrammetric processing. These limitations arise from large shadows and spatially variable characteristics of brightness and contrast. The latter caused by haze or uneven development of the scanned film or contact print. These inhomogeneities can not be balanced by standard image processing tools affecting the whole picture in the same way. Differentiated image enhancement can be achieved by dodging. Originally dodging is used to balance radiometric differences at the edges of adjacent images in mosaicking processes. But in this context it is very useful for brightening up shadows and equalizing varying radiometric characteristics within images. For this purpose it might be appropriate to apply dodging twice with different cell sizes for basic statistics calculation. The results then need to be combined into one image afterwards.

For haze reduction and sharpening the unsharp mask-tool is appropriate. It is common to most image processing software. A large mask applied with low intensity decreases the impact of haze. A small mask applied with high intensity emphasises contours at changes of gray levels in the imagery.

2.3.3 Determination of missing parameters: Both types of historic imagery mostly lack at least some of the parameters required for processing in softcopy photogrammetry systems. Hence the only way to apply methods of digital photogrammetry is to derive inevitable parameters from metadata or the images themselves. At least the focal length of the used camera can often be found in the labelling of war time aerial photographs as well as in the data box of more current mapping images (Figure 3).

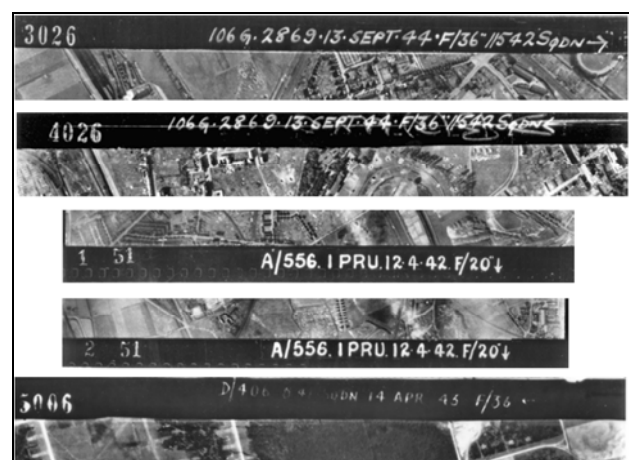


Figure 3a: Labelling of reconnaissance imagery (LUA 2006, p. 52)



Figure 3b: Data box of present aerial photograph (LVerMA NRW 2002)

If no specification for the focal length can be found in the imagery, it can often be extracted from metadata like tables or databases or in plots as depicted above. Further reference can be drawn from documentation of cameras or film layouts (Figure 4 / Table 1).

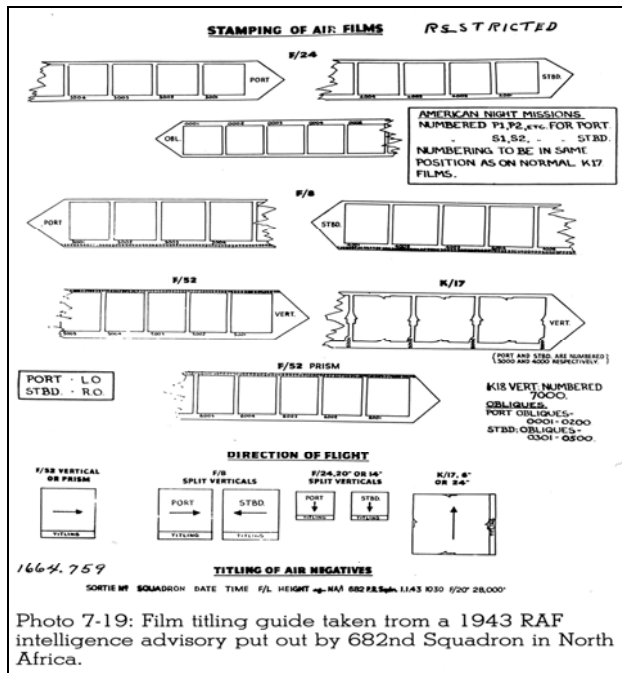


Figure 4: Film Tiling Guide taken from a 1943 RAF intelligence advisory put out by 682nd Squadron in North Africa (Stanley 1981, p. 229)

Name	Lens focal lengths (inch/mm*)	Number of images	Film-/Image-format(s) (cm*)
RAF: F.8 II + III mapping camera	20 = 508 36 = 914 40 = 1016	250	18 x 23
RAF: F.24 multipurpose camera	5 = 127 8 = 203 14 = 356 20 = 508	125 250	13 x 13
RAF: F.52 RAF: F.63 reconnaissance camera	14 = 356 20 = 508 36 = 914	250 500	18 x 23
USAF: K-series especially: K8AB K17	6 = 152 12 = 305 24 = 610	Up to 500	13 x 18 23 x 23

*) mm-/cm-values rounded

Table 1: British and American reconnaissance cameras with focal length and image format (LUA 2006, p. 47)

As mentioned before in some aerial photographs and in reconnaissance imagery in particular fiducial marks can not be found or their shape does not allow precise measurement. Furthermore the required coordinates for fiducial marks and the principle point are mostly not available. These values can not be reconstructed from the imagery, indeed, but a virtual coordinate system can be constructed. This is accomplished by measuring present fiducial marks, assuming their geometrical centre as principle point and as origin of the coordinate system at once. If fiducial marks are not available artificial marks need to be marked and measured in the photographs. This can be done using special software like the Geosystems Fiducial Builder.

Provided that images are digitised and all required parameters are available the photogrammetric workflow can be initiated.

2.4 Triangulation of historical aerial photographs

Triangulation is the key to three dimensional measurements in stereo models from aerial photographs. Furthermore it provides the possibility to extract an elevation model of the photographed area. On this basis orthophotos can be generated as well.

For triangulation inner and exterior orientation need to be provided. Inner orientation is established on the basis of the previously determined values for focal length and the coordinates of fiducial marks of the camera.

Providing exterior orientation requires adequate sources for ground control points (GCP's). Trigonometric fix points can hardly be identified in aerial photographs. Likewise measuring new points in the current environment for referencing historic images representing a different stadium of the imaged area appears rather costly. Therefore a continuous spatial reference is the most appropriate source for GCP and checkpoint coordinates. A geo-referenced map can provide horizontal coordinates, whereas a digital elevation model (DEM) supplies area-wide vertical positions. With these sources coordinates are available for any location like corners of buildings, infrastructure crossings etc.. The allocation of such points always has to be carried out considering possible changes of landscape features in the time between image capture and the last revision of the used reference.

Another issue that comes up using historical imagery is the much lower resolution of historical film. It complicates the recognition of edges and corners especially at the margins of very bright objects which therefore sometimes can not be located confidently.

Especially in former mining districts like the Ruhr Area differences in surface heights from mining subsidences between image capture and acquisition of available DEM's are most likely. Taking these into account is very difficult since data on changes of elevation is rarely available.

Because of numerous distortions especially in war time imagery incorporating additional parameters in triangulation can help to account at least for some of the unknown geometric errors.

After initial triangulation GCP's and check points need to be examined for errors. Again it must be considered if any modification of landscape features or changes in surface heights might have lead to large residuals at erroneous reference points.

If triangulation results can not be improved anymore, exterior orientation parameters can be taken over for further processing.

2.5 3D-feature collection

In the context of historical research stereoscopic vision as well as the possibility to obtain object heights is very helpful for identifying landscape features like industrial facilities. To estimate the probability of their contribution to toxic spillages knowledge of their function is vital for research on handled substances. Additionally measuring the height of depositions or the depth of pits and holes can be realised. On this basis volumes of fillings with problematic waste can be determined.

2.6 Terrain extraction

With an oriented stereo-pair of aerial photographs a DEM of the imaged terrain can be calculated automatically. With historic imagery heavy deformations and spiky surfaces can occur in extracted models because of distortions, errors in interior orientation parameters and deficient radiometric quality. Rough surfaces can be smoothed to some extent and distortions might not disadvantageously affect terrain analysis for small areas of interest.

In cases where automatic terrain extraction does not deliver usable results, contours of the desired terrain can be digitised manually in the stereo model. From digitised 3D-features a triangulated irregular network (TIN) can be deduced and converted to a raster DEM afterwards (Figure 5).

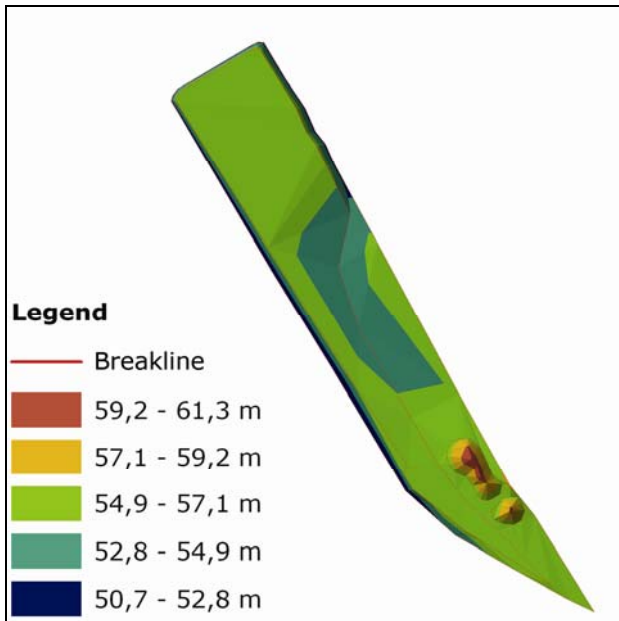


Figure 5: Surface-TIN derived from digitized contour lines

2.7 GIS analysis

To derive the required information on probable pollution in a desired area GIS analysis can be carried out on the basis of digitally collected features and extracted surface models from aerial photographs. Further important sources are data from maps, plans and archival records. They provide vital information that can not be extracted from imagery. For vector feature data analysis is done by aggregating and intersecting the data of all analysed times. At the end features or parts of

features remain that might contain pollution from former land use (Figure 6).

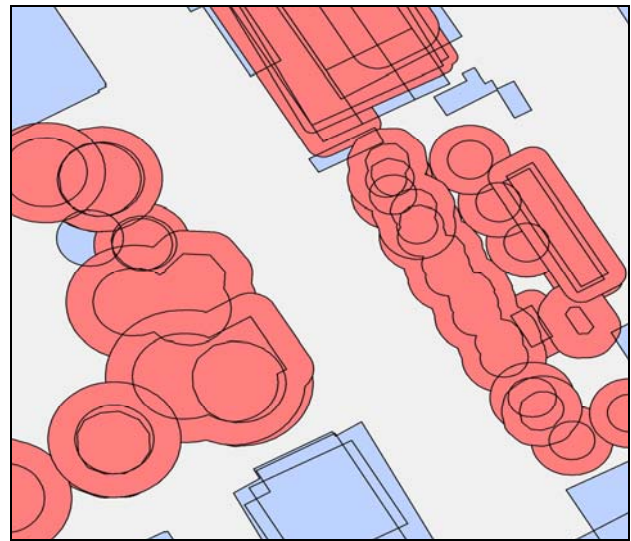


Figure 6: Possible pollution from industrial facilities caused by spillage and the impact of bombings in WW II. (Redecker & Dödt 2006, p. 48)

Changes in terrain heights can be evaluated by calculating differences between elevation raster data from identical areas of different times. With appropriate GIS-tools even volumes can be determined approximately (Figure 7 / Table 2).

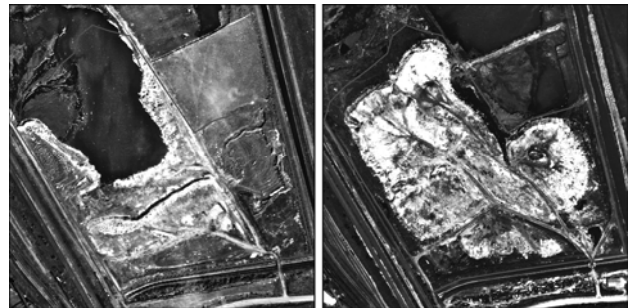


Figure 7: Development of landfill site between 1959 and 1969.

Year	2D_AREA [m ²]	3D_AREA [m ²]	VOLUME [m ³]
1969	173239	176724,20	12743029,90
1959	173239	175281,38	11490821,94
Volume			1252207,96

Table 2: Results of volume calculation

2.8 Visualization of results

Two different kinds of visualization for the results from GIS-analysis in historical research can be differentiated.

- diachronic maps, showing situations of a site from different times in one map (Figure 8).

- synchronous maps, representing one certain situation in a sites development (Figure 9).

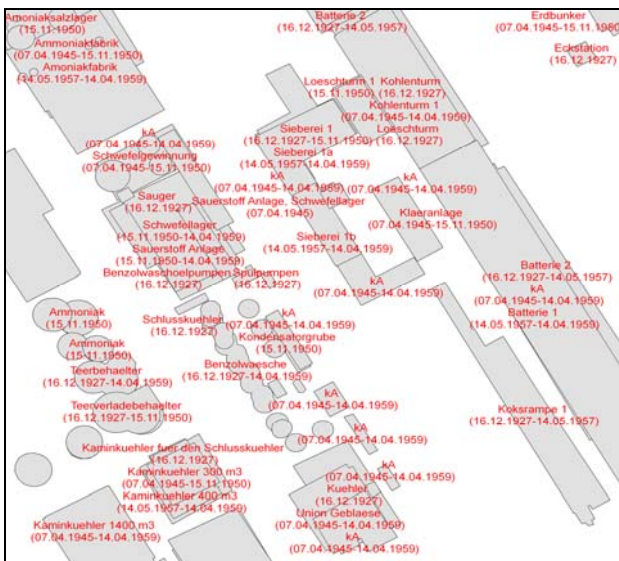


Figure 8: Diachronic map showing all features with their time of existence. This analysis is based on the evaluation of aerial photographs and plans from different times (Redecker & Dodt 2006, p. 49)



Figure 9: Synchronous map showing the impact sphere and evident damages of bombings derived from aerial photographs taken in 1945.

3. CONCLUSION

In practice, there is, however, at least some information available on the photographs themselves or relevant missing data can be deduced from other existing information so that processing with photogrammetric software is possible. Although metadata deduced from existing information will not

meet strict photogrammetric accuracy requirements the photogrammetric process of aerotriangulation can be accomplished. Its results will certainly not be up to the standards of photogrammetric mapping, but the measurement inaccuracies will be known as a result of the triangulation (residuals of GCPs and check points) and can be considered in the GIS-analysis. Regarding the context of historical research positional accuracy is less important than the semantic information gained from the photographs.

Comparing the “traditional” mapping of contaminated sites using mirror stereoscopes or multiscope to the softcopy photogrammetry approach with aerotriangulation and digital stereo models the latter has the following advantages:

- dynamic adjustment of zoom level
- enlargement up to single pixels
- dynamic adaptation of histogram stretch
- known error of triangulation
- comfortable stereoscopic vision with high-end computer graphics
- direct three-dimensional feature collection
- GIS-integration
- higher accuracy for feature collection
- extracting surface models of former terrain
- orthophoto production

The benefits from this technique are obvious, and the fact that the results might not completely meet photogrammetric accuracy standards is acceptable as long as possible displacement errors are known.

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