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The Processing of Photogrammetrically-Generated Elevation Models in the Ruhrkohle AG Geographical Information System (GIS)

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ABSTRACT

For many years the analytic photogrammetry has been a proven economic method for data captures for the Ruhrkohle AG own GIS. Particularly considerable are the recording of the earth movements due mining and the production of differntiated Digital Elevation Modells (DEM).The case study shows the solution for the following task: Production of a DEM within an environmental compatibility audit with the means of analytical photogrammetry.
In future times methods of digital photogrammetry - especially in connection with remote sensing techniques and GIS - will be of growing significance. Another example presents the first results gained in the automatic correlation of aerial pictures.

1. THE USE OF PHOTOGRAMMETRY AT RUHRKOHLE AG

Any mining activity will inevitably have an impact on the environment. There has therefore long been a regulatory requirement for avoiding or reducing conflicts of interest. Increasing sensitivity to environmental problems and increased statutory demands for planning and licensing procedures are leading to increasingly accurate, detailed, comprehensive additional information having to be gathered and processed. After intensive preliminary studies and system comparisons, Ruhrkohle AG therefore selected the geographical information system ARC/INFO in 1988/89 as a resource for fulfilling the new environmental requirements. In the meantime, the data for numerous tasks has been processed by this system, including data for licensing procedures with environmental compatibility audits, spoil heap planning and monitoring, and data processing for property, mining damage and pre-existing pollution. It must be remembered that the data available in the system constitute a major criteria for the success of a GIS. Depending upon the task, different demands are made on the data in respect of accuracy, integrity, homogeneity and current applicability. This makes the acquisition and updating of data extremely important. Due to the costs involved, emphasis must be placed upon problem-orientated, and above all cost-effective, data acquisition. Photogrammetric and remote sensing are essential to the acquisition of primary data. The cost-effectiveness of these methods is constantly improving due to new developments in digital photogrammetry, GPS-supported vertical aerial photography and high-resolution satellite- or aircraft-mounted scanner platforms [Ackermann, 1991].
Since the beginning of the 1980s photogrammetry and remote sensing have been used for the following purposes by Ruhrkohle AG:

- Photogrammetry:

  - Extensive surface coverage of three-dimensional earth movements,
  - Documenting and recording spoil heaps,
  - Documenting industrial sites,
  - Digital terrain models for various purposes.

- Remote Sensing:

  - Land use classification ,
  - Vegetation monitoring,

- soil moisture mapping,
- multitemporal analysis.

For years photogrammetry has proved to be the most economic method of generating the digital elevation models required by Ruhrkohle AG. This is particularly applicable due to the frequently very large areas involved and the inherent variety of requirements. In this connection it is also important that the photogrammetrically-generated data can be reprocessed in the GIS (model generation, combination with other data, analysis and derivation of parameters).
Since 1986 photogrammetric measurements has been carried out internally, on efficient analytical equipment made by Zeiss (Oberkochen). In addition, tests on the suitability of digital photogrammetry methods for use at Ruhrkohle AG commenced at the beginning of 1995. Initial analyses have been carried out in the fields of automatic elevation models and orthophoto production. Analytical photogrammetry should be partially replaced by digital photogrammetric methods in the medium term. In addition, the integration of photogrammetry, image processing and GIS on a single platform should considerably improve the coordination of the components, particularly when processing high volumes of data.
A brief explanation of the photogrammetric methods hitherto used for the measurement of earth movements and the generation of digital elevation models is given below, followed by a report on objectives and initial experiences with digital photogrammetry.

1.1 Measurement of earth movements

Detection of earth movements due to mining is necessary for Ruhrkohle AG for a number of reasons:

- Fulfilment of official requirements for monitoring the surface,
- Improving the forecasting process for earth movements,
- Assessing patterns of damage to buildings and the infrastructure,
- Various planning purposes.

The results from two measurement periods are compared within the scope of deformation analysis, using analytical photogrammetry, which is currently the most economical method. The topographical features used, particularly manhole covers, are measured by suitable vertical aerial photography (cross-flights) in six to nine pictures, so that horizontal and vertical accuracy of points of 2 to 3 cm is achieved. However, a considerable amount of processing is required, so that this is considered a practical case for the use of digital photogrammetry (see point 3).

1.2 Digital elevation models

Digital elevation models are required for various purposes and with differing requirements. The main fields of use are:

- Displaying elevations in extraction areas,
- Documenting spoil heaps,
- Documenting relief in industrial plant,
- Planning measures to prevent mining damage (e.g. regulation of outfalls and ground water, dyke construction),
- Planning other building projects (e.g. the redevelopment of former mining sites).

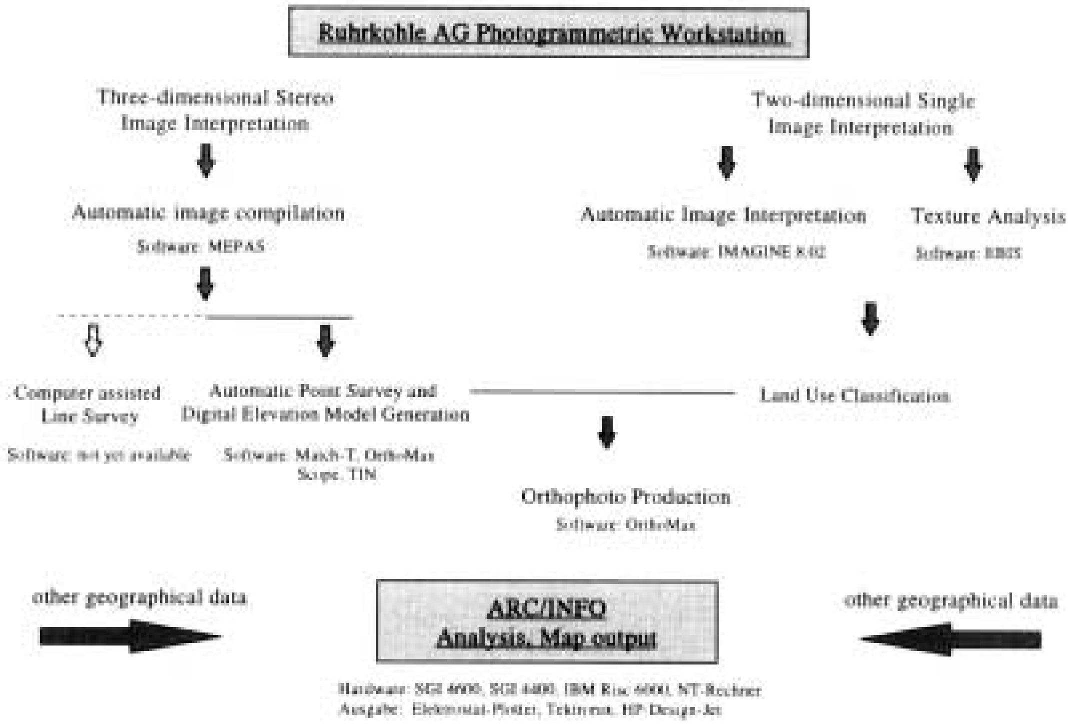
The most frequent common feature of the various applications is the compilation of elevation data with other information to simulate:

- earth movements occurring,
- the ground water situation,
- precipitation drainage conditions,
- ecological aspects; and to derive typical parameters from an elevation model, e.g.,
- gradients and changes therein,
- outfall catchment areas,
- non-draining basins.

Diverse forecasts of future developments with and without coal mining have to be provided within the scope of the licensing procedure. If applicable, various alternatives with different precautionary and regulatory measures have to be compared. Finally, the data already acquired must be updated regularly and the forecast effects checked. The term "environmental monitoring" is used in this respect.
The following sample application is intended to illustrate the demands made and show how analytical photogrammetry methods are currently used.
In 1994 Ruhrkohle AG required a homogenous, up-to-date elevation model of an area measuring approximately 300 km2 in the North-West Ruhrgebiet. The background was the preparation of an outline industrial plan with an environmental compatibility audit under German environmental compatibility planning legislation. The outline industrial plan is intended to secure long-term anthracite production from three mines. Due to the requirements of various specialist assessors in this case, breaklines were recorded, in addition to a raster adapted to the situation. In general, a surface-covering 50 m raster is regarded as sufficient in ecologically less significant areas and/or areas with a deep water table, although distinctly unreliable elevations are calculated in the interpolation areas between the survey points. A complete record of the breaklines was made in the ecologically valuable areas specified by the assessors, or the areas with shallow water tables. Compression of the raster to 25 m was regarded as necessary in part.
Vertical aerial photography of this area on a scale of 1:6000 was carried out in March 1993 for this task. CIR photographic material was used for better compilation and interpretation.
Zeiss C-Planicomps were used for compilation, with subsequent aerotriangulation using the BLUH program system. The 50 m point raster was surveyed over the whole surface in a second stage. Surface patches and outlines were measured at the same time. To save time, some of the breaklines were measured at the same time as the raster survey, and some in a separate stage on the Zeiss Planicomp P1. All the data was loaded into ARC/INFO, where the elevation model was simulated using the TIN module, in which compilation with other data and derivation of parameters was accomplished using the TIN and GRID modules.
Considerable effort was required to complete the task, which should be reduced by the use of digital image survey methods in future projects.

2. DIGITAL PHOTOGRAMMETRY

In recent years digital photogrammetry has become the buzz word for the future of photogrammetry. A start was thus made on examining, testing and preparing digital photogrammetric processes for operation use at Ruhrkohle AG at the beginning of this year, within the scope of an international research project. The fundamental principle of all the considerations is the integration of digital image processing, digital photogrammetry and the geographical information system into a single entity, to achieve an optimum combination for fast, economic processing of large volumes of data of various origins.
In order to select a suitable configuration for the purposes of Ruhrkohle AG, the Institute for Photogrammetry and Surveying (IPI) at the University of Hannover was commissioned to prepare a critical summary of possible configurations in 1994 [IPI, 1994]. The following configuration was subsequently acquired.



The following points from the entire programme of the project will be emphasised within the scope of this paper.

2.1 Automatic image compilation

In order to be able to fully accomplish the generation of digital elevation models in the specified visual material, compilation of the image material, including pass point measurement, should take place on the same hardware platform.

Image compilation, which is of great importance, particularly when high-quality digital elevation models are to be derived from large blocks of image material, is very involved. A distinct advance can thus be made in the direction of rationalisation and increasing cost-effectiveness particularly by automating image compilation.

Ruhrkohle AG is testing the MEPAS program, developed by IPI Hannover [Wang, 1994] in operational use on test blocks with images on different scales for this purpose. The requirements of Ruhrkohle AG should provide stimuli for further development, in order to achieve optimisation of the program for specific requirements.

2.2 Generation of digital terrain models

The principal focus of the work is the generation of digital terrain models as automatically as possible. Considerable progress has been made all over the world in recent years, particularly in the field of automatic image correlation and point measurement. Appropriate software has appeared on the market in the meantime. Ruhrkohle AG has decided on the parallel use of the Match-T system, by Messrs. INPHO of Stuttgart, and OrthoMax, by Messrs. AUTOMETRIC, Earth City, USA.

This decision is the result of a thesis [Fischer, 1994], which recommends the use of different programs, depending upon the structure (rural or urban) of the area undergoing processing. The ultimate critical factors for practical use at Ruhrkohle AG are whether the elevation models (see 1.2 above) required

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can be generated more economically using digital photogrammetry than they can by analytical photogrammetry, whilst maintaining at least equivalent quality.

The following should be specified individually:

- Single point accuracy in automatic correlation
  (Influence of scanning resolution, scanning error, grey scale value distribution in the raw images, image scales, texture, etc);
- The effect of different mesh sizes on the quality of the elevation model
  (Reproduction of terrain movements, pattern of contour lines, processing speed for large volumes of data);
- Reprocessing of the raw data by the existing simulation programs
  (e.g. TIN, SCOPE, MODELL, WINSURFER from aspects such as processing speed for mass data, quality of approximation, data handling, visualisation, etc);
- Integration of the results into the GIS and the derivation of typical parameters
  (gradient, exposure, basins, etc);
- Comparison with existing digital elevation models obtained by analytical photogrammetry, allowing for the recording strategy for the breaklines and linear features.

The initial results obtained will be briefly presented later (see 3).

2.3 Detecting earth movements

The importance of detecting earth movements caused by mining was mentioned in 1.1. Amongst others, a publication by Prof. Ackermann [Ackermann, 1994] was seen by Ruhrkohle AG as an opportunity for the significant detection of three-dimensional movement between two periods from automatic digital elevation model generation combined with intelligent pattern recognition processes for a variety of non-indicated points.
However, we are still only beginning our considerations in this respect, so no details can yet be discussed.

3. COMPARISON OF AUTOMATIC POINT MEASUREMENT WITH AN ANALYTICALLY MEASURED REFERENCE GRID, USING THE EXAMPLE OF THE PARK STADIUM IN GELSENKIRCEN

The purpose of this test is an initial examination of the correlation quality of the Match-T program. A thorough examination of all the sources of error within the scope of data generation, hardware settings and the digital elevation model calculation method is being undertaken as part of the research project mentioned. The results which were obtained using the standard program settings are interpreted below. The pictorial material used was taken from aerial photographs taken in 1990.

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Image scale	1:4000
Image material	Colour
Longitudinal overlap	60%
Terrain	Park Stadium, Gelsenkirchen
Scanner	Vexcel VX 3000
Resolution	1000 dpi/25 microm/b & w

The vertical aerial photographs were compiled on a Zeiss P1 analytical analysis unit and triangulated with the BLUH bundle block program. The orientation of the images can be loaded into Match-T for correlation. Inaccuracies between the reference measurement on the analytical plotter and the result of correlation therefore cannot be attributed to differences in triangulation.
The Park Stadium in Gelsenkirchen was selected as a test area. A dense, analytically measured grid is present, so that the area is sufficiently accurately reproduced by the **reference measurements** and the derived contour lines permit a sufficiently accurate representation of the surface. The reference survey contains a record of single points, i.e. a regular grid survey and breaklines. The upper and lower edges of the grandstands were digitised as breaklines, whilst a 10 m grid was used to survey the pitch. As a survey of surface topography is necessary for our problem, the roof of the grandstand was defined as a surface patch. The accuracy of the reference survey can be given as dz = 10 cm. These measurements were loaded into the TIN program running under ARC/INFO to calculate an elevation model. Following triangulatory intermeshing, contour lines (Fig. 3) were derived for the purposes of visual verification.

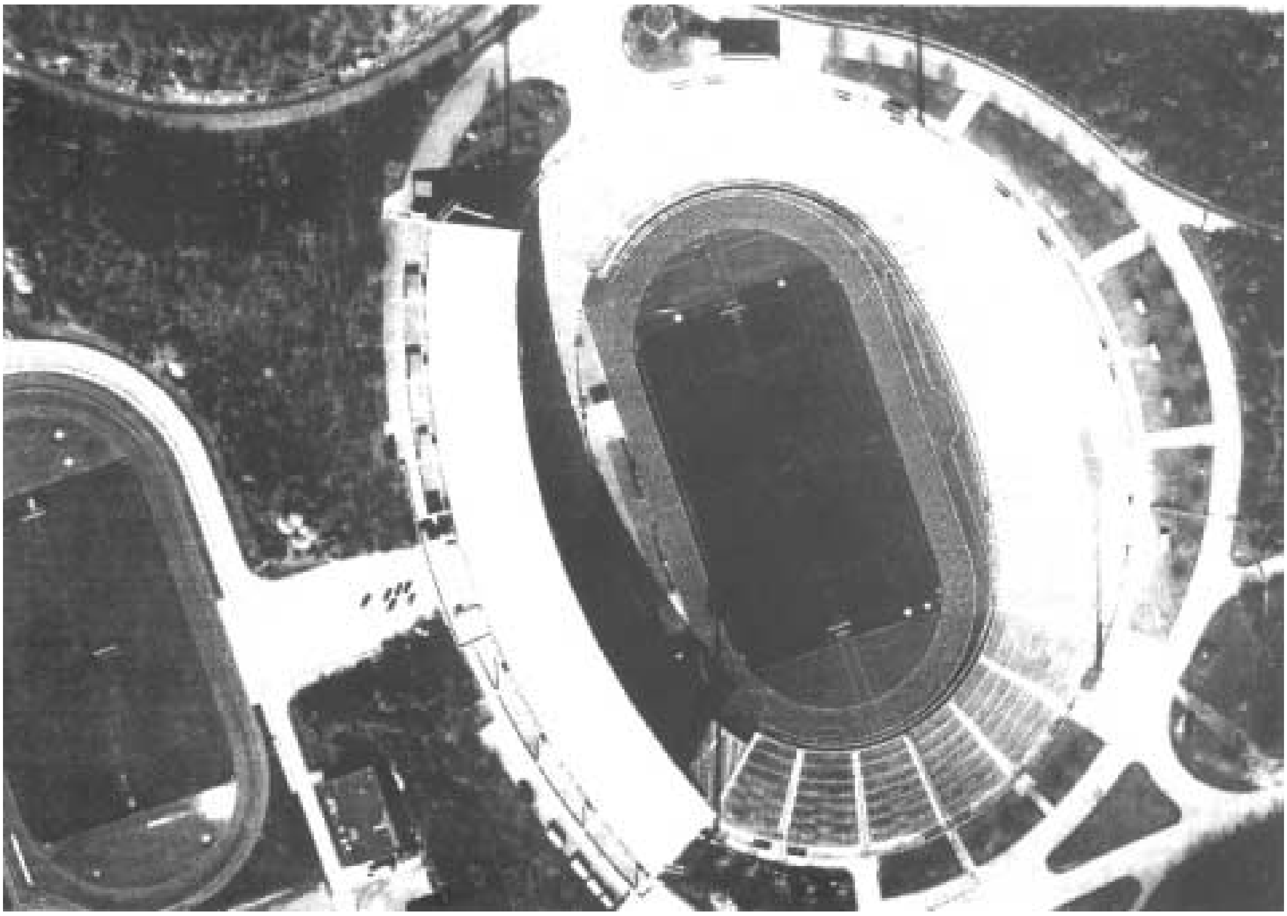

Figure 1: Parkstadion.

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In the case of **automatic point measurement with Match-T**, a 1 m grid was used for correlation. As an artificial structure was involved here no interference, for example from vegetation, need be anticipated. The internal program settings and filters for "flat" terrain were therefore selected in this case. In order to assess the quality of the automatic point survey, no external line measurements, such as surface patches or breaklines, were introduced. In exactly the same way as for the reference heights, an elevation model was calculated in TIN from the correlated points and contour lines derived using identical parameters.

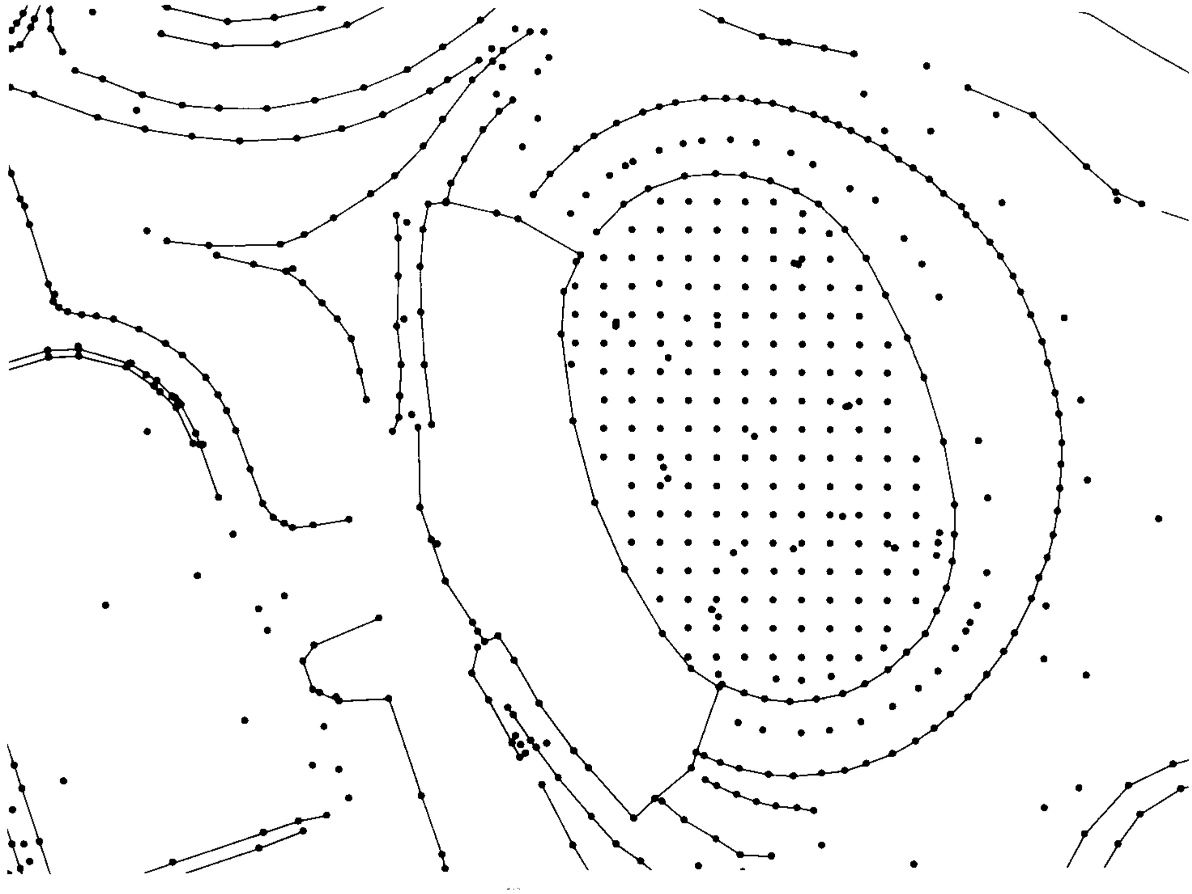

Figure 2: Reference data.

Fig. 1 shows a geographically referenced vertical aerial photograph as a view of the "Park Stadium" test area. The points and lines surveyed, and the surface patch on the grandstand roof, are shown in Fig. 2.

The display of the contour line plan of the analytically measured points (Fig. 3) also shows where the surface patch of the grandstand roof is located. The curve on the side opposite the grandstand shows a gradient rising to the upper terraces. The irregular line in the centre of the terraces can be explained by a glance at the position of the reference points (Fig. 2). At this point a comparatively significantly larger mesh size exists, so that a depression occurs in the elevation model. The contour line on the pitch shows that it is not completely flat, contrary to initial expectations.

The overall smoother contour lines in Fig. 4 are due to the considerably greater number of points in the raster recorded. The pattern of the terraces is generally correctly shown. The aforementioned depression on the eastern terraces cannot be explained by a comparison of single points at this location. The contour lines inside appear to differ more than those in the reference model. However, it must be considered that the resolution of the matched grid is 1 m, which is accompanied by enhanced detection of small differences in height.

The grandstand roof has been greatly smoothed by the settings selected for correlation and not displayed at its true height. The transitions from the height of the grandstand roof have also been

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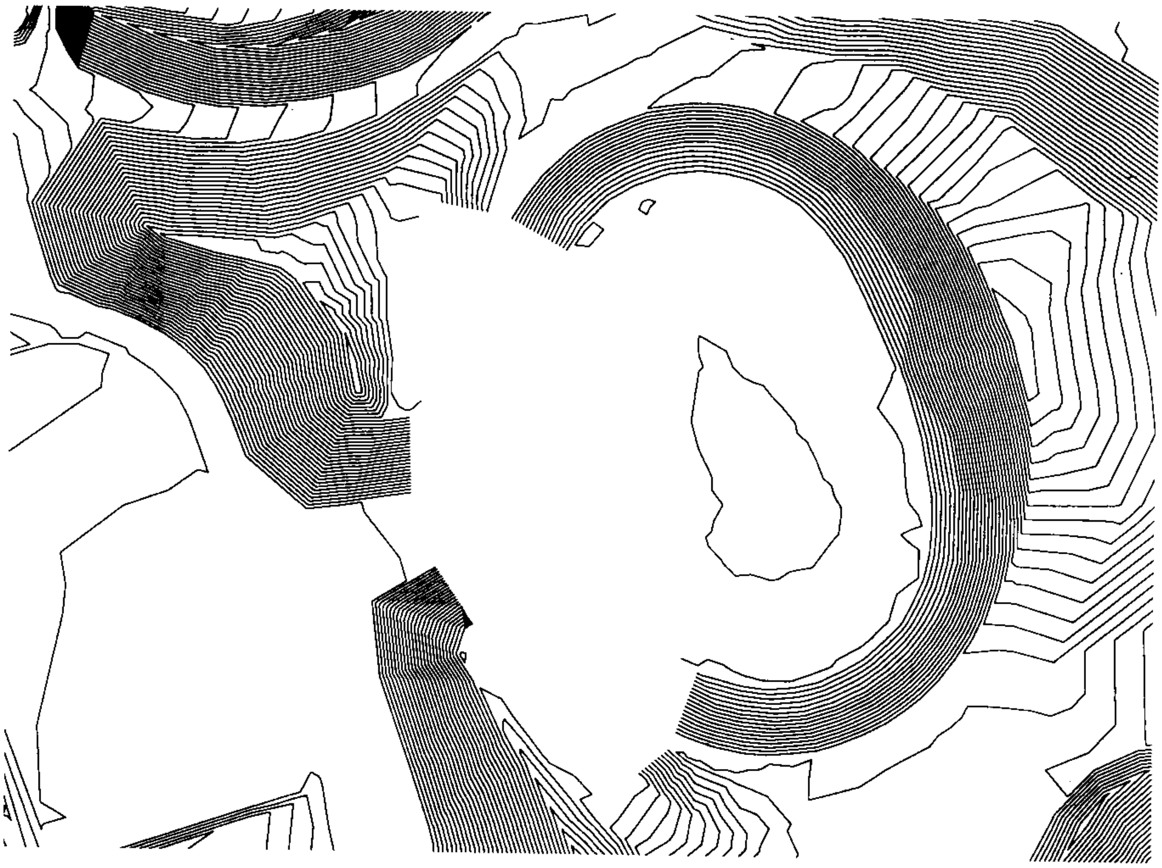

Figure 3: Reference DEM.

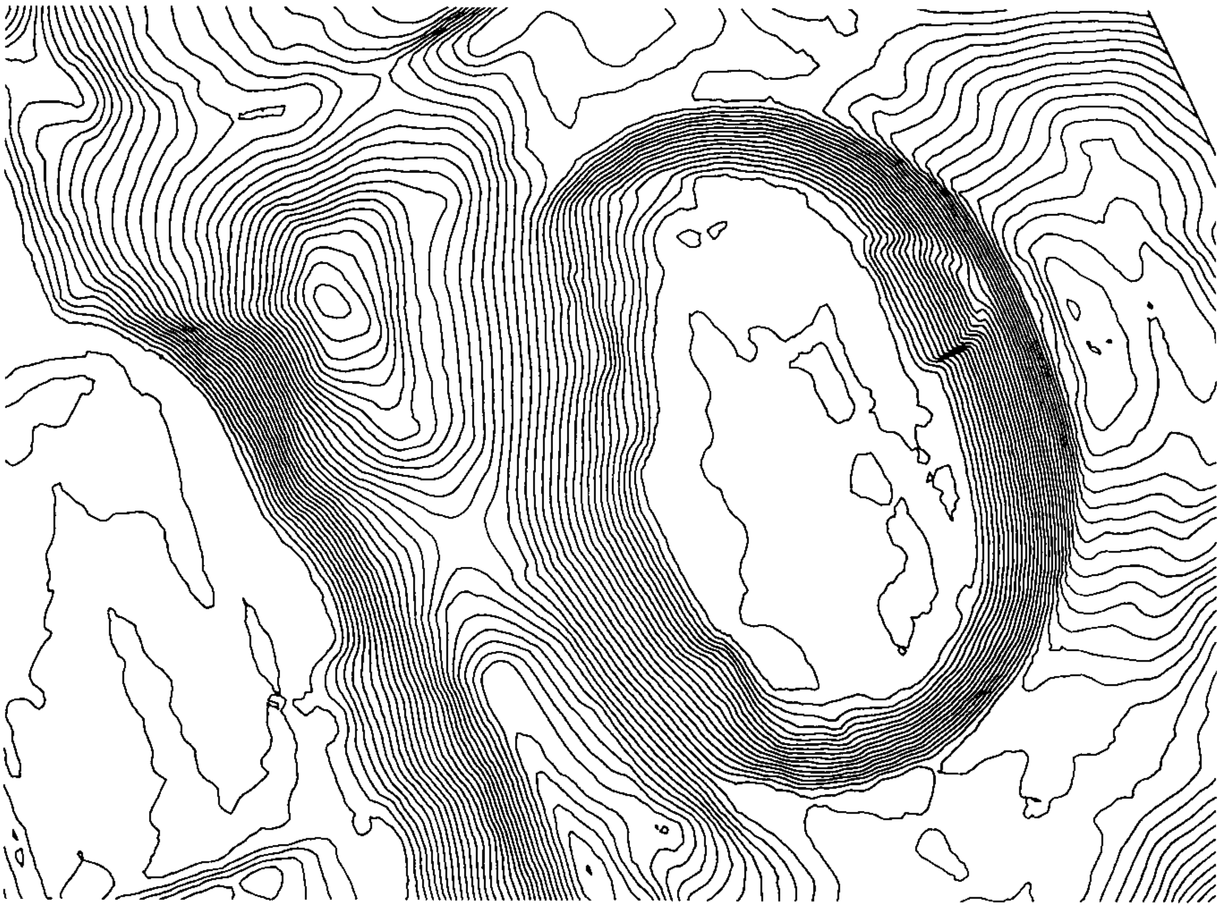

Figure 4: DEM by Match-T.

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influenced. At this point it will be clear that it is not possible to dispense with surface patches in the correlation process either.
A statistical analysis of individual points between analytically recorded and matched points did not appear to produce any practical results here. Great differences in height appear in the vicinity of the grandstand roof, as the height of surrounding points is influenced by the height of the grandstand, as mentioned above. Nevertheless, only slight deviations from the reference grid occur within the stadium, the overall result of which is that a comparison of individual points can only be made with specific reference to the subject.
However, the initial tests carried out here show the potential and accuracy of using such systems in complex areas. We thus visualise extensive potential applications within the scope of tasks at Ruhrkohle AG.

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