CAD-BASED PHOTOGRAMMETRY FOR 3-D RECONSTRUCTION OF LARGE OBJECTS

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ABSTRACT

The photogrammetric reconstruction of large buildings is normally characterized by difficult environmental conditions, complex image configurations and large numbers of images. In this paper a hybrid photogrammetric system is presented which consists of well-proven analogue imaging devices in combination with a low-cost image scanner and a CAD-integrated digital multi-image compiling system. Practical results of large engineering projects are used to discuss experiences and system performance.

1 INTRODUCTION

1.1 Objectives

The photogrammetric reconstruction of large engineering objects such as manufacturing plants, power stations, buildings or bridges is not a new application. Various examples have been published showing the successful use of photogrammetry for the measurement of complex environments (e.g. Kotowski et.al. 1989). However, it is still an ambitious engineering task due to the complexity and structure of many objects, and the general technological and economical situation.

This report presents practical experiences using a hybrid low-cost photogrammetric system. The system has been applied to a number of projects which can be characterized as follows:

- recording of large objects
- processing of natural, non-targeted object structures
- medium accuracy requirements
- hidden object areas
- difficult environmental conditions
- results processed as 3-D CAD data

The spatial dimension of the objects varies between approx. 10m to 200m. The required accuracy is about 1:5,000 to 1:20,000 of the maximum object dimension. The object surfaces can not be marked by artificial targets and image processing is mostly performed manually.

Due to practical conditions and the complexity of many objects, variable imaging configurations are required. The photogrammetric network is always designed as a convergent multi-image configuration whereby local restrictions often lead to non-optimal ray intersections. As a result, multi-image orientation is performed by bundle adjustment. The datum problem is normally solved by locally provided control points. The configuration of control points and camera stations must enable simultaneous camera calibration.

1.2 Solutions

The highlighted sequence in Figure 1 describes the hybrid photogrammetric process used in the following applications. It is based on analogue photogrammetric image acquisition. Using low-cost desktop image scanners enlarged paper prints can be digitized with sufficient geometric resolution and accuracy. Finally, the photogrammetric image evaluation is performed with interactive digital processing systems that are integrated into a CAD environment. This method combines the advantages of a well-proven imaging technology with those of digital image and CAD processing.

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1 Modified version of (Luhmann 1997)
2 SYSTEM DESCRIPTION

2.1 Image Recording and Digitization

All projects have adopted the Rollei 6006 medium-format metric camera, with focal lengths between 40mm and 150mm using ILFORD FP4 b/w film. Its geometric resolution is estimated around 100 lp/mm. The original negatives have been enlarged to paper prints of 18cm x 18cm (scaling factor 3).

A simple desktop scanner, the HP ScanJet, has been used for image scanning. Geometric resolution (400 dpi), radiometric resolution (8 bit) and geometric accuracy (30-50µm) do not match the performance of the camera/film system. However, scanning of enlarged reseau images yields to an appropriate pixel size (approx. 21 µm in the original film negative) and enables the numerical correction of almost all geometric failures down to image accuracies of 10µm (Bendler 1994).

Recently a second image scanner, the Agfa DuoScan, has been used (600 dpi, 8 bit). As compared with the HP ScanJet it shows a significantly worse accuracy with a strong non-linear behavior. Later results of bundle adjustment have shown that the Agfa system does not fulfill the requirements even for reseau images.

2.2 Image Archiving

Large and complex image configurations (e.g. >100 images) require systematic management and archiving of the images. For this purpose an image data base has been developed using MS-ACCESS which allows the storage of relevant image information either during image acquisition on-site, or during later scanning. The situation in the field is described by relatively simple imaging attributes (e.g. north, south, top, bottom ...) and the parameters of exterior orientation. The object itself is defined by a number of predefined object attributes such as 'main arch', 'west entrance', 'dome' and so on.

Figure 2 and Figure 3 show examples of data structures and report generation.

![Figure 2](image1)

**Figure 2:** Example of data relations of the image data base

![Figure 3](image2)

**Figure 3:** List of images matching the query statement

2.3 Photogrammetric Processing

The interactive multi-image compiling systems PHIDIAS (Benning & Effkemann 1991), PHIDIAS-MS (Benning 199???) and Rollei CDW (Goddling & Fellbaum 1995) have been used. In order to transfer data between both systems special data conversion programs have been developed. The first version of PHIDIAS was restricted to a two-image compiling mode. The newer version of PHIDIAS-MS is integrated into the Microstation 3-D CAD environment and is suited for interactive processing of up to 8 images at once. The CDW package benefits from robust estimation of approximate values which is otherwise an extremely time-consuming task in complex applications with a large number of images (Goddling & Fellbaum 1995).
3 Projects

Table 1 summarizes the technical data of three practical applications. The relatively high number of established control points, as well as the number of acquired images have been chosen to provide a safety margin. In all projects access to the object was limited to a few days so that possible problems in orientation and object reconstruction had to be avoided in advance.

<table>
<thead>
<tr>
<th>Local object recording</th>
<th>Workshop hall</th>
<th>Powder Tower</th>
<th>Pont Adolphe</th>
<th>Main Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>dimensions [m]</td>
<td>100 x 60 x 8</td>
<td>12 x 12 x 10</td>
<td>180 x 15 x 60</td>
<td>120 x 30 x 38</td>
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<td>Lenses</td>
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<td>40mm</td>
<td>60mm, 150mm,</td>
<td>60mm</td>
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<tr>
<td>control points</td>
<td>29</td>
<td>40</td>
<td>80</td>
<td>34</td>
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<tr>
<td>control point accuracy</td>
<td>5mm</td>
<td>1-3mm</td>
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<td>acquired images</td>
<td>60</td>
<td>96</td>
<td>250</td>
<td>96</td>
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<td>processed images</td>
<td>60</td>
<td>48</td>
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<td>1:300 - 1:500</td>
<td>1:470 - 1:850</td>
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<td>HP ScanJet llc</td>
<td>HP ScanJet llc</td>
<td>Agfa DocuScan</td>
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<td>19µm</td>
<td>21µm</td>
<td>19µm</td>
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<td>image size</td>
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<td>2700 x 2700</td>
<td>4320 x 4320</td>
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<td>368 MB</td>
<td>1080 MB</td>
<td>1710 MB</td>
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<td>CAP</td>
<td>Nawe-Opt, CAP</td>
<td>PHIDIAS-MS</td>
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<td>object points</td>
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<td>approx. 60</td>
<td>approx. 330</td>
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<td>mean image accuracy</td>
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<td>12µm</td>
<td>16µm</td>
<td>7.5µm</td>
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<td>&lt; 10mm</td>
<td>5mm</td>
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<td>&lt; 3-5mm</td>
<td>2-4cm</td>
<td>3-6mm</td>
</tr>
</tbody>
</table>

Table 1: Technical project data

3.1 Workshop hall

CAD-oriented information and planning systems for workshop management require geometric data of the workshop environment, manufacturing facilities, machine positions and supply networks. Together with Deutsche Aerospace DASA at Varel the ability of photogrammetric data collection for the 3-D reconstruction of a workshop floor has been investigated (Harms et al. 1994). Using PHIDIAS 1.0 / InfoCAD for this project (Figure 5) a complete 3-D model has been produced (Figure 4 and Figure 6).

Due to the architecture of the hall, the acquired images were mainly taken from the longitudinal aisles in the hall. The final image configuration was therefore laid out in strips, leading to a weak configuration in some parts of the block. The following orientation problem could be solved by a number of additional control points.

Figure 5: User-interface for photogrammetric processing

Figure 4: CAD model of the processed workshop hall

Figure 6: Rendered view of the workshop floor
3.2 Powder Tower

For monument preservation purposes detailed plans of the historic Powder Tower of Oldenburg had to be generated. The final results will include a stone-by-stone registration of the exterior and the interior walls in the form of a complete 3-D CAD model. A geodetic net of control points has been established inside and outside the building. Images were taken from all around the object including camera stations from higher positions using a hydraulic lift (Figure 7: Example image of the Oldenburg Powder Tower Figure 8).

3-D Point determination of the exterior walls was performed by intersection in the PHIDIAS program. The total facade consists of approximately 32000 object points (4 to 8 points per stone). This task could only be handled by a direct superimposition of graphical data onto the images (Figure 7: Example image of the Oldenburg Powder Tower Figure 8). In the interior a stereoscopic reconstruction of the untextured wall of the dome was necessary. This data was collected on a Zeiss P3 analytical plotter running PHOCUS software. The measuring results of both systems were transferred to AutoCAD for further processing. As a result two-dimensional drawings and a cylindrical projection of the exterior facade have been produced (Figure 9) (Tecklenburg 1995).

Figure 7: Example image of the Oldenburg Powder Tower

Figure 8: Superimposition of 3-D CAD data

Figure 9: Cylindrical projection of the facade

Figure 10: Projection of the principle arch
3.3 Pont Adolphe

In co-operation with Administration Ponts & Chaussées of Luxembourg the suitability of low-cost photogrammetric systems for the documentation and measurement of bridges has been investigated (Gay & Hartenstein 1995). As an initial project the Pont Adolphe (built in 1902) has been chosen. At one time this was the largest stone bridge in the world (Figure 12). A complete 3-D model of the bridge has been requested in order to derive ground views, side views and projections of the major arches (example in Figure 10).

Especially in this project a lot of images look very similar so that unique image identification is only possible if image archiving has been carefully done. For this purpose the above mentioned image database was a helpful tool that enables even a second operator to work easily with the image material.

The bridge spans the Petrousse canyon in the city of Luxembourg. It consists of two separate longitudinal parts covered by a common roadway. The bridge is approximately 180m long and 60m above the river, with a maximum span of 80m. The steep slopes of the canyon, the river and the vegetation on the slopes create very complicated environmental conditions. Numerous photographs must be taken from a 30m hydraulic lift. Due to very limited camera stations a number of overlapping images must be taken by panning the camera. Figure 11 shows the configuration of those images used for final data collection.

3.4 Main Station Oldenburg

The Main Railway Station of Oldenburg has been chosen as a test object for a student's diploma thesis (Bahn & Krite 1998). The major topic of the work deals with the superimposition of real images onto the CAD model in order to generate ortho-images of the facade (texture mapping) (Streilein 1995, Pomaska 1996).
4 REFERENCES


