The 'Digital Projector'
Raytracing as a tool for digital close-range photogrammetry

Klaus Hanke [a,*], Mostafa A. Ebrahim [b]

[a] *Institute of Geodesy, University of Innsbruck, Technikerstrasse 13, A-6020 Innsbruck, Austria*
[b] *Civil Engineering Department, Assiut University, Assiut, Egypt*

Abstract

In close-range applications, digital methods are increasingly used. In addition to the software and techniques which were adopted from aerial photogrammetry, new strategies for the restitution and presentation of digital data have been developed. The 'Digital Projector' is a strictly photogrammetric approach using raytracing techniques and off-the-shelf software to provide 3D models with complete texture. It works regardless of the shape of the object while allowing digital presentation ('photomodels') with numerous derivative results (e.g., orthoimages and animations). © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Easy handling, the comfortable and clear processing with widely accessible computer equipment and the advantages of low-cost hardware and software have lead to an ultimate success of digital methods found in all fields of photogrammetry today. The availability of digital images for close-range applications with Photo-CD and digital cameras as well as the valuable amount of data shows that this field is highly suitable for digital photogrammetric solutions.

A typical result of architectural photogrammetry are facade maps. In addition, 3D-grids, surface and volume models in connection with CAD systems can be produced using photogrammetric restitution. As in other surveying fields, the use of CAD systems facilitates continuation during further data processing and administration.

Rectification of photographs is a widespread method in close-range photogrammetry. Originally, only photos of planes were rectified, later this was extended to differential rectification of photos for even curved surfaces. Draping these rectified images to the surface of an object is a very common way to perform texture mapping (e.g., Streilein, 1996; Promaska, 1998). These approaches have their limits since they are restricted to surfaces of the form $z = f(x, y)$. This means that the third coordinate is only a (more or less) smooth mathematical function of x and y. This is not surprising since all these approaches originated from aerial applications.

* Corresponding author. Fax: +43-512-507-2910; E-mail: klaus.hanke@uibk.ac.at

The problem will be illustrated by an example. In most cases, it is impossible to describe architectural objects in the above mentioned easy way because they contain, e.g., ledges, alcoves, niches and hidden parts. Especially, old buildings very often have rather irregular surfaces. In addition, a simple partitioning of the entire object into single facades will not always be useful or possible.

2. The concept of the 'digital projector'

2.1. Basic ideas

The concept of the 'Digital Projector' approach is, on one hand, a new rigorous digital photogrammetric tool. On the other hand, it takes into account the demand for an object-oriented, 3D reconstruction of arbitrary objects in close-range applications. In this context, object-oriented means that the whole process aims to virtually restitute the object in 3D, not only to draw maps or create orthoimages.

Contrary to conventional 'rectification' of metric photographs the 'Digital Projector's' concept is a strictly object-oriented 3D restitution of the whole object with almost no conditions or limitations. The approach is based on a consistent reversion of the situation during exposure.

2.2. Details of the process

The process of an object reconstruction for a virtual computer model happens in three individual steps (see Fig. 1). In the first step, the camera's interior and exterior orientation as well as the objects' characteristic wireframe (i.e., lines) have to be reconstructed. Appropriate manual or semiautomatic measurements in all available images can be done using any mono or stereo system as long as they result in a 3D outline of the object (Streilein, 1996; Hanke and Ebrahim, 1997). To get a consistent solution of the entire object these elements are computed during a photogrammetric bundle adjustment where a probable and homogenous result of the whole measurement system is guaranteed. There is a large number of photogrammetric systems available for this task, ranging from very advanced to rather

low-cost hardware and software. After this first step, unrestituted or hidden parts may still exist.

In the next step, within a common CAD environment the object's wireframe is reviewed by the user and if necessary completed (see Fig. 1b). At this stage additional measurements (tape, theodolite, etc.) can be introduced. After that, the 3D model will be manually closed defining faces between the structure lines. Subsequently, it will be investigated for leakage by performing a first rendering process. The surface model that arises during that step will be used as a kind of 'projection screen' and may have a very different level of detail.

The third step is the actual reprojection of the photos (Hanke and Ebrahim, 1996). Similarly as with a slide projector, selected photos are projected onto the surface model using raytracing techniques. The selection of photos is based on visibility and projection direction. Therefore, the object must be divided into individual sections, each related to a 'Digital Projector' (Fig. 1c). The 'Digital Projectors' have the same interior and exterior orientation as the related cameras. The necessary values are obtained from bundle adjustment. This step can be performed using any rendering or raytracing software that offers 'spotlights' (directed light source) for image projection (e.g., 3D Studio). This kind of software is commonly available and needs no additional programming to perform this projection. The result of this step is a textured 3D computer model of the object ('photomodel') from which other required results can be derived later.

2.3. Characteristics of the approach

The approach is general and can be used in many applications other than architecture, e.g., for archaeological documentation, in forensic and medical applications. Because the restitution is strictly object-oriented there is no problem combining different kinds of photos of the same object. Freeform or smoothed surface elements and even NURBS are as well suitable for 'projection screen' as simple geometric primitives. The type of surface is only restricted by the modelling capability of the utilised CAD software. The use of close shots for interesting details and overview shots to include neighbouring objects
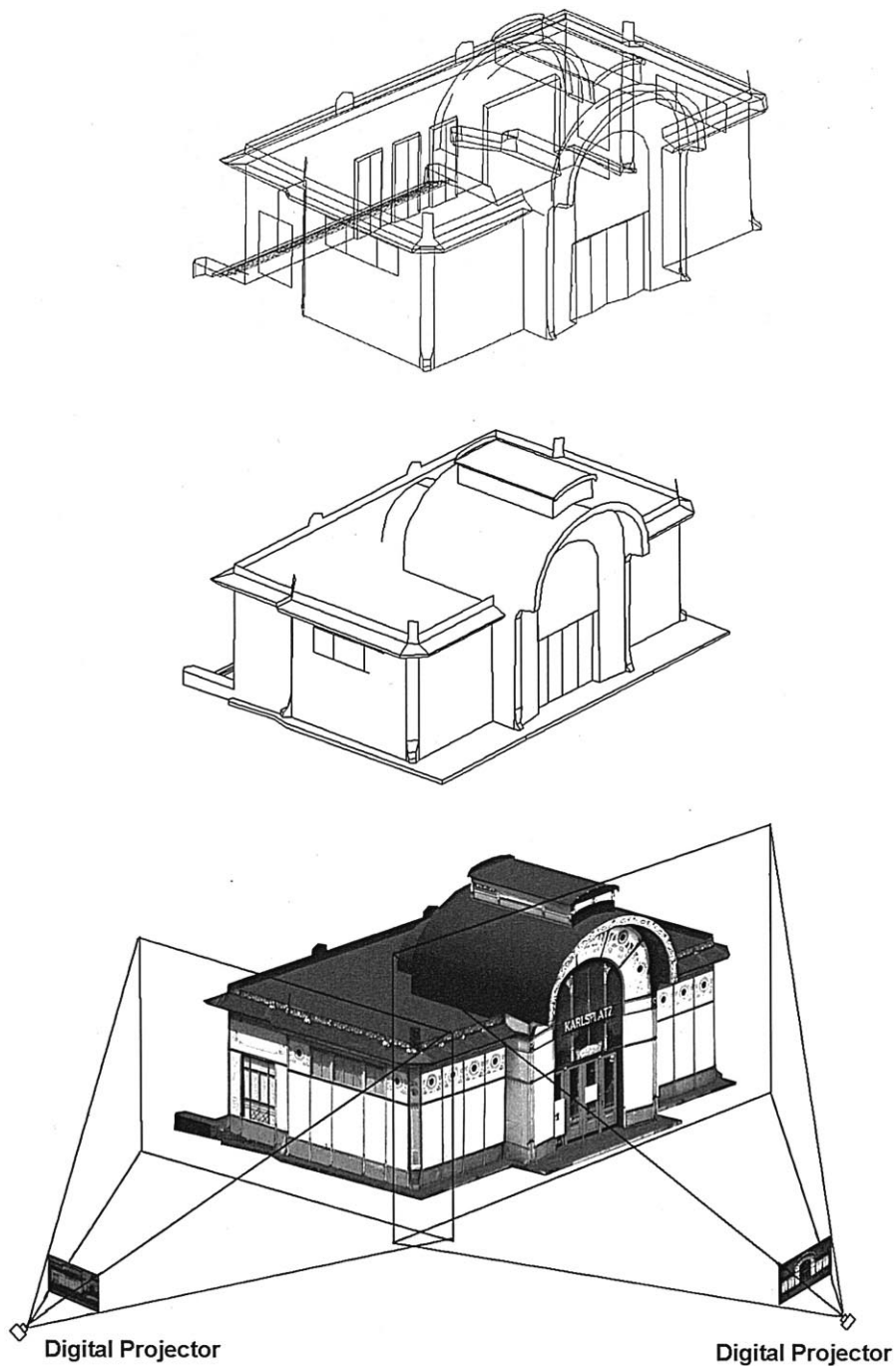
Fig. 1. The steps of 'Digital Projector' approach illustrated at international CIPA test project 'Karlsplatz, Vienna': (a) wireframe model, (b) surface model ('projection screen'), (c) photomodel.

with less resolution of projection is also possible without problems and shows the flexibility of the approach. There is also no principal problem to combine the inner and outer parts of an object. In

this case, some of the projectors just have to be inside for digital projection to the interior walls.

3. An application: the medieval living tower 'Ottoburg', Innsbruck

The approach was tested in a number of architectural applications with very different characteristics. One of the most fascinating was the Ottoburg project. The building is a medieval living tower of the 15th century in downtown Innsbruck which is of very high historical value and has been used as a restaurant for the last centuries. It has a very complex structure and typically, no part has a simple or regular surface. For practical reasons, two different cameras were used for data acquisition. A Hasselblad SWC (super wide-angle) medium format camera was used for a basic bundle arrangement around the building. To get the roof area, additional photos with a small format camera were taken from neighbouring house roofs. In addition, close shots (e.g., around the entrance area) were taken to increase the density of points and the level of details and image resolution for projection. Because the building stands on one side close to the river, it was necessary to add narrow angle photos from the opposite bank of the river to image building parts hidden in the photos taken so far.

The 6×6 cm Hasselblad images were scanned using a desktop scanner, whereas the 35 mm photos were digitised via Photo-CD (Hanke, 1994; Hanke and Weinold, 1995). In total, 25 photos were used and about 1450 3D-points and 2700 surface elements were measured. Fifteen images have been used for digital projection to the surface model.

4. Visualisation, animation and virtual reality modeling language (VRML)

The photomodel is also the data storage concept. Further results can be derived from this model, e.g., by parallel or perspective mapping to an arbitrary viewing plane. Fig. 2 shows a set of reduced orthoimages of three facades of Ottoburg (original scale 1:100). The high level of details in this model is illustrated in the entrance area of the building (Fig. 3). Even animations (fly-over and walk-around) can be created easily from this concept.

A very promising way to visualise 3D data is to create 'virtual worlds', not only for computer games but also for 'more serious' applications. The VRML is a new standard format describing 3D data in a way that they can be inspected interactively by the user (Vacca, 1996). Using this description format, the models can be viewed, turned around or animated in
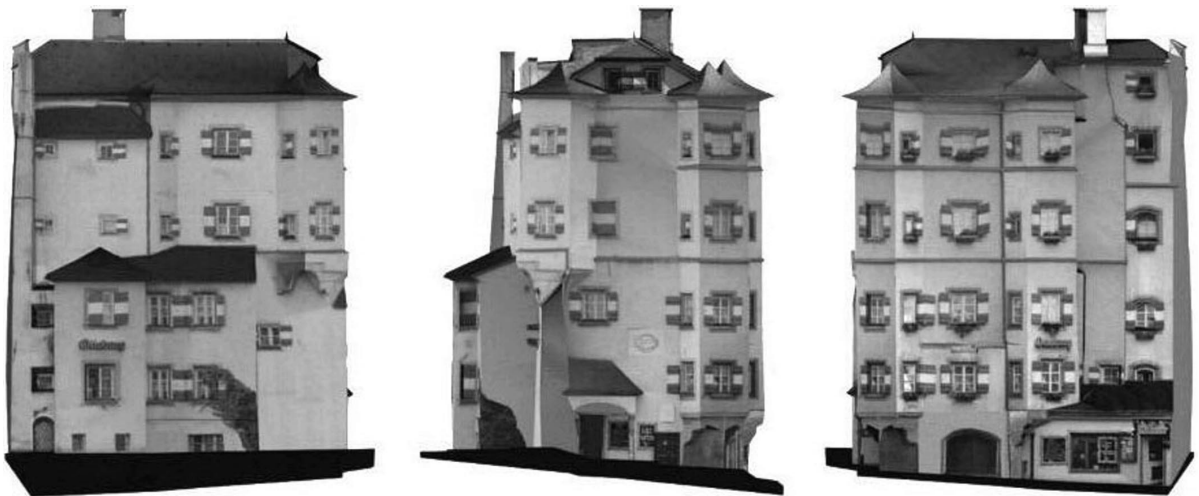

Fig. 2. Derived orthoimages from 'Ottoburg' photomodel.

Fig. 3. Detail of 'Ottoburg' photomodel.

real-time even on a PC. Thus, VRML is suited to create, e.g., interactive environments, virtual museums, visualisations and simulation bases on real world data, from photogrammetric data.

5. Conclusions

There is a fundamental change with regard to the results of a surveying project. Following this development, the 3D data will be administered in structured information systems that do not prescribe or restrict their further use. Plans and maps, perspective views or profiles and even virtual reality animations are examples of derivative products of a coherent database of the object surveyed. The way of using the derived data is not limited by this database. The

kind of presentation will depend on the end user requirements and the specific application at hand.

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