TERRESTRIAL LASER SCANNING – APPLICATIONS IN CULTURAL HERITAGE CONSERVATION AND CIVIL ENGINEERING

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KEY WORDS: Cultural Heritage Conservation, Engineering, Industry, Terrestrial Laser Scanning, Colour Scanning, Close Range Photogrammetry

ABSTRACT:

Laser scanners are used more and more as instruments for various tasks in cultural heritage conservation. Especially old buildings and archaeological sites are relevant to offer a variety of applications e.g. the surveying of static or simply the visualization and precise modelling for data archiving purposes.
The developed IMAGER 5003 is a state-of-the-art, high precision, high speed laser scanner, which provides accurate measurements. The IMAGER 5003 measures range and intensity images at the same time, with a one to one correspondence between these both images with respect to the angles: The range image generates geometric dimensions of the environmental scenes, whereas the reflectance image generates a photographic like impression of the scanned environment which is used for feature extraction, visual inspection, object segmentation, and surface classification. For visualisation tasks the scan data can be combined with colour information: For this purpose either a special high resolution line scan camera – developed by the German Aerospace – or a standard digital array camera can be used. This paper introduces from a practical point of view into visualization and modelling techniques by using the laser scanner IMAGER 5003. The paper describes features and methods of the system, and shows up two applications in the field of cultural heritage conservation and civil engineering.

1. INTRODUCTION

Reconstructing buildings and scenes is an important topic not only for surveying but also for data visualisation and archiving. Whereas in recent years the main focus of research concentrated on 3D reconstruction based on 2D image data, laser scanning technology gets nowadays more and more popular. To get more realistic impressions, geometric 3D data of laser scanners can be combined with 2D colour camera information. In order to fulfil three dimensional geometric measurements with colour information, we combine the laser scanner IMAGER 5003 either with a high resolution CCD line scan camera or a standard CCD array camera respectively. This paper introduces into the main features of the used hardware and shows methods of how (colour)-scans can be used for visualisation and modelling.

2. HARDWARE FEATURES

In the first part of this chapter the main features of the physical devices are presented. Then an overview about the software is given, and methods used for cultural heritage applications and civil engineering are shown.

2.1 The IMAGER 5003

The visual laser scanner IMAGER 5003 of Z+F (see figure 1) is an optical measuring system based on the transmission of laser light [3],[6]. The environment is illuminated on a point by point basis and then the light reflected by an object is detected. The laser scanner consists of a one-dimensional measuring system in combination with a mechanical beam-deflection system for spatial survey of the surroundings.

figure 1: The figure shows the IMAGER 5003

The laser scanner is designed for non-tactile, high performance measurements with high robustness and accuracy [7],[8],[10]. This is necessary for exploration by surveying industrial plants and production halls, as long down-times in production have to be avoided; but it is also required for cultural sites like churches or castles where people visiting the site should not be disturbed. Due to the large field of view of the scanner, 360° horizontally (azimuth) and 320° vertically (elevation), the scene to be modelled has to be surveyed only from a few points of view.
Beside the 2D reflectance information the laser scanner 5003 has in addition 3D range information. Both – reflectance and 3D range information – correspond one by one with respect to the azimuth and elevation angles. So by extracting features in an accurate way, the combination of image processing methods and 3D geometric information is possible.

The system itself has different scanning modes, which differ in spatial point distance. It can be selected according to requirements between Super High Resolution (20000 pixel per 360° horizontally and vertically) and Preview (1275 pixel per 360° horizontally and vertically) mode.
The acquisition time is very short: The mode for example which is most popular in industrial applications takes just 3.22 minutes for a full 360° scan. An overview about the predefined modes is shown in the table below.

	Nb Pixel (Horiz./Vert.)	*Nb of Pixel for 360° [deg] Scan*	*Spatial point distance in 10m*	*Acquisition Time*
Super High Resol. (default noise filter)	20000 / 10000	200 Million	3.1 mm	6.44 min
Super High Resol. (low noise filter)	20000 / 10000	200 Million	3.1 mm	13.28 min
High Resolution (default noise filter)	10000 / 5000	50 Million	6.3 mm	3.22 min
High Resolution (low noise filter)	10000 / 5000	50 Million	6.3 mm	6.44 min
Middle Resolution (default noise filter)	5000 / 2500	12.5 Million	12.5 mm	1.41 min
Middle Resolution (low noise filter)	5000 / 2500	12.5 Million	12.5 mm	3.22 min
Preview	1275 / 625	0.8 Million	50.2 mm	25 sec

figure 2: The figure shows the different scanning modes for the Imager 5003

Another big advantage of laser scanning technology is that it can be operated in total darkness as well as in daylight. This facilitates measurement, as no additional illumination is needed.

2.2 CCD Camera Hardware

The next section introduces the main features of the DLR line scan camera [4], [9].

figure 3: The figure shows the high resolution DLR line scan camera.

The DLR camera Eye Scan

This camera is developed in a common project between an industrial company and the Deutsches Zentrum für Luft- und Raumfahrt (DLR) for environmental documentation purposes. The camera consists of a rotating unit which rotates an integrated CCD line chip 360° to achieve a full view of the environment. By using line chips with each 10.000 elements a very high resolution can be achieved with the imaging. Three lines (RGB) provide 14 Bit information for each pixel of the environment and guarantee a high dynamic range.

The resulting images consists of a maximum of 10.000 by 500.000 pixels, and are stored by a specially developed frame grabber onto the hard disk of a computer. A typical scan using a special optical lens system by 35mm optical focus length takes about 3 min (daylight) and up to 60 min (dark indoor illumination), mainly depending on the ambient illumination conditions and the number of rows to be measured with the camera.
The software for the camera enables the user to set typical camera settings like e.g. the shutter speed. For improving the homogeneity of the colours for different illumination conditions, shading correction tables can be chosen (e.g. daylight or indoor illumination). The software also includes a package for the geometric calibration, which enables the recalculation of the raw data into a geometrically calibrated image.

Setup for combining camera and image data

In the photogrammetric field, a couple of techniques are known, to map RGB data onto range data: Assuming that the distortions of both systems is already geometrical recalibrated, the overall mapping formula must in some way contain a translation (3 unknowns), rotation (3 unknowns) and perspective projection: In the following it will be shown, how this 6-dimensional parameter space can be reduced to one parameter.

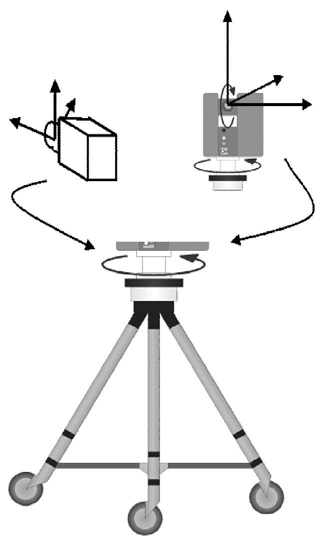

figure 4: The figure shows the basic principle of the data acquisition (see text).

The scanner and camera acquisitions are performed one after the other: After a scan with the IMAGER 5003 is finished, the DLR Eye Scan camera is set onto the same tripod, by fixing an adapter onto it (see figure 4). This adapter ensures that the location of the optical centre of the camera is identical to the one of the scanner unit, as well as both horizontal rotation axes are. Thus the only unknown parameter, which must be calculated to transform both co-ordinate systems into each other, is the horizontal angle.

Beside the big advantage of its brilliant resolution, the panoramic camera has the disadvantage of being not very flexible as it has to be fixed on the tripod. So a second method for colour mapping (as stand-alone or in combination with the panoramic camera) was developed, by using a free held standard CCD camera.

2.3 Standard CCD Camera

Alternatively to the DLR panoramic camera the colour information can be taken with a standard CCD camera: In the applications shown in Chapter 4 an Olympus CAMEDIA was used, which is a low cost 2.5 Mega pixel rgb camera (see figure 5).

figure 5: The figure shows the Olympus CAMEDIA C 2500L: 2.5 Mega pixel (effective 2.3), with 1712 x 1368 Pixel

3. SOFTWARE

Two software tools, which are specially developed and optimised for the IMAGER 5003 exist: The ZFLaserControl (former Z+F Viewer) is the basic software for operating the scanner. Light Form Modeller is the software to convert 3D point clouds into CAD objects and offers a comfortable interface to standard CAD programs, as well as the fast visualisation of the point cloud of up to 256 scans.

3.1 ZFLaserControl

Scanning

The operator software is designed for the scanning in the field (see figure 6). The software is very easy to handle by using predefined settings for the scanning. The software enables the operator to select between five predefined buttons to set the application specific scanner parameters (see figure 2). By selecting the preview mode for example a preview of the area to be scanned in detail can be measured and afterwards selected to be rescanned using a higher point density.

Visualisation

Directly after the measuring, the first results can be seen on the computer: Usually the reflectance image is used to get a photorealistic impression of the scanned area. It is similar to a black-and-white photo and therefore does not require much experience to interpret. There exist two different modes for its visualisation: The first mode ("overview mode") enables the viewer to see the whole scanner area, whereas the second mode ("perspective view mode") shows the raw data projected perspectively [1], and so gives the viewer a three-dimensional feeling of the environment. This projection is calculated fast, so the viewer can control the actual viewing direction simply by moving the mouse.
After each scan, the surveyor can see directly in the reflectance image objects which have been captured. When objects are hidden by other objects, it may be necessary to scan this region from another point of view.

Another way of checking the scan is with the grey-coded range image. It is the corresponding image to the reflectance image, viewing the same area, but range is displayed rather than reflectance. In the range image, every range has its own grey level; the greater the distance to an object is, the lighter the object is represented. Objects which are near by the sensor are almost black. As this is not natural to the human eye, some experience is needed to get useful information from this view. The range image is important for the control of the ambiguity interval, as the operator can easily see which objects are far away and therefore are measured with a lower point density. This image can also help the user to decide where exactly to take the next scan.

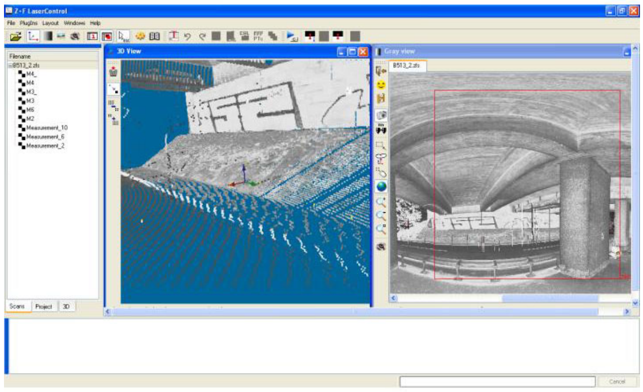

figure 6: The figure shows the ZFLaserControl desktop

To get an overall view of the scanned area, the 3D window is essential. All measured points are transformed to 3D so that the whole point cloud is shown as a three dimensional image which gives a good impression of the scanned region. The user can turn the object and zoom in and out to see the object from any point of view. Like in the reflectance image, hidden areas can be easily detected in this view. All these different modes are presented in chapter 4 (Applications).

Measurement Features

Before taking the scanner to an application, a geometric calibration has to be performed. Once having calculated these parameters, simple measuring features allow the user to get the most important measures on site and a feeling for the dimensions. The user just has to click on two points in the reflectance image, and the program calculates the distance between them. By using this feature, first on-side measurements can be taken already in the field which allows the user to perform already data evaluation tasks "on the job".

File export functionality

To get independent from the internal data format a special export function can be used. This function enables the conversion from the internal raw data format into calibrated grid data, describing equidistant angles between two pixels. For saving this resampled grid data, a couple of standard image formats can be selected, which is a big advantage especially for data archiving purposes.

Colour mapping

The ZFLaserControl functionality provides a camera calibration method (using Tsai`s method [11]) for any CCD array camera by querying some camera specific parameters. To perform the colour mapping itself, some corresponding points have to be marked, in the scan as well as in each camera image. One feature of the developed mapping method is the automatic colour adjustment to compensate the different illuminations between the different images [1].

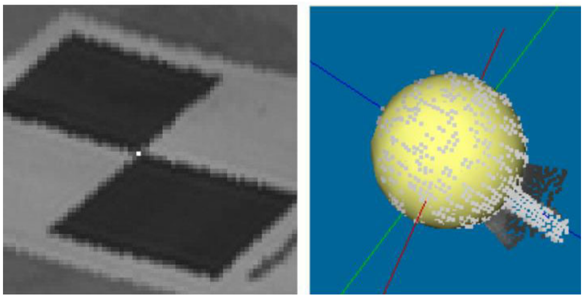

figure 7: The Z+F software provides a method for finding two different types of predefined targets: *Left*: The "chess pattern" Target [2], *Right*: The "Bowl" Target

3.2 Light Form Modeller

Light Form Modeller (LFM) has been developed specifically by Zoller + Fröhlich to convert 3D point clouds into 3D CAD models. Conversion from point data to CAD objects is achieved by the application of analysis algorithms which have been developed to facilitate swift points-to-primitives translation.
Modelling of small or large structures dictates that significant numbers of images need to be taken from a number of different viewpoints and consequently, building a 3D CAD model can quickly become a very complex undertaking. For this reason, LFM provides seamless support to the user to allow rapid registration of multiple images from multiple viewpoints in order to compose the 3D CAD model.
Various modules are available:

LFM Register

This package enables users of LFM to be able to register or join together neighbouring scans in order to form a group of scans or a "point cloud". It also enables export data from the Imager 5003 scanner via DLL to a number of complimentary CAD packages (Microstation, AutoCAD, PDS, PDMS, ..).

LFM Generator

It generates a database of points from the registered scan data. This database of points can then be viewed directly in LFM Server or through LFM Server in a CAD package such as Microstation or AutoCAD. It is possible to generate a database of points of up to 256 scans. This capability far surpasses other software on the market and enables the user to be able to hold all these scans in view and then zoom into the area of interest and then increase the resolution of the scan to view in normal mode.

LFM Server

The Imager 5003 produces extremely large amounts of 3D data (see figure 2). This means that loading individual scans can be a time consuming process. It is not desirable to have a work process which continually involves the opening and closing of individual scans. The user of high resolution laser-scanned data wishes to access the area of interest within the point cloud quickly and be able to view high resolution data. Projects can reach 1000 scans or more, which can mean clouds of points containing 50 billion points or more. LFM Server is highly efficient at navigating these very large point clouds and serving the points data to view in high resolution.

figure 8: The figure shows a 3D point cloud of several scans of high density like they can be visualised by using LFM Server

LFM Viewer

Where a costumer is using a CAD package not linked to LFM Server then they may wish to compare an existing CAD model with the real world by reading the CAD model into the cloud of points. Where this function is required then LFM Viewer can be used as it is CAD engine based. In this instance the number of scans that can be viewed simultaneously will be limited to a handful by the processing power and RAM of the computer but it will be possible to compare the real world with the design model by working around the model in this fashion.

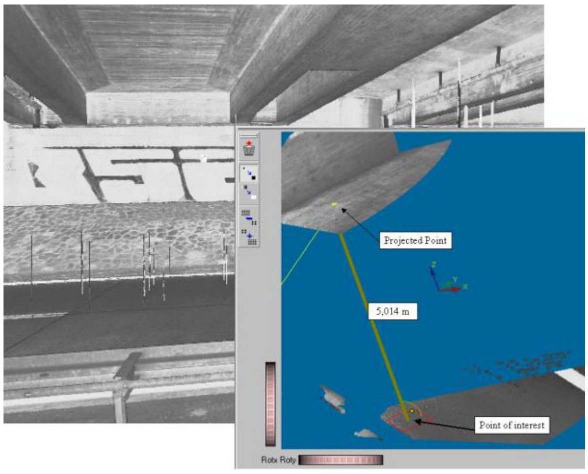

figure 9: The figure shows the reflectance image of a highway bridge and a simple "on the job" measurement: The user can control the distance of a selected spot on the road to the bridge directly after the scan just by marking it in the reflectance image.

LFM Modeller

Where accurate and semi-automatic fitting of the point cloud data is required then LFM Modeller is used. An example of this work is tie-in and work package modelling in the process industry or modelling of equipment detail close to the car-line in automotive plant. Modelling using the LFM Server with the

CAD package can be used more for infrastructure where accuracy is not quite as crucial e.g. Walls, ceilings etc.

4. APPLICATIONS

In the following examples are presented using the Z+F Hard- and Software tools.

4.1 Traffic construction

Laser scanners are used more and more as surveying instruments for various applications in traffic construction analysis. Especially tunnels and road conditions are relevant to offer a continuous monitoring. As traffic is increasing steadily the infrastructure has to be in proper conditions. With traffic and transported goods increasing, detailed information of the network (clearance of bridges and tunnels, rut etc.) has to be monitored.

The task in this project was, to show the process from measurement of highway bridges by scanning over determining the condition in terms of the height of the bridge to a surface analysis, all relative to the road surface and an initial coordinate system (for details see [5]). To get an overview about the conditions of the static, first measurements "on the job" can be done (see figure 9). The results of the modeling process are shown in figure 10.

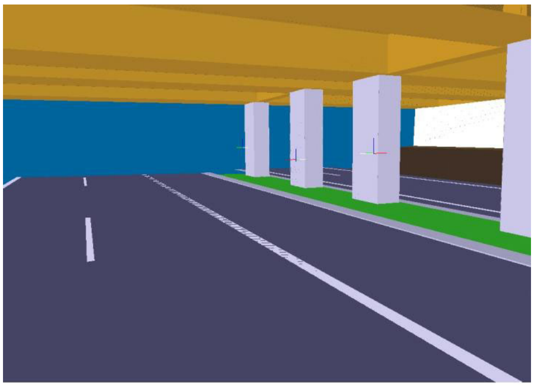

figure 10: The figure shows a highway bridge represented as CAD model

4.2 Schloß Neuschwanstein

The next example deals with visualising and modelling the study and the throne room in Neuschwanstein castle (built between 1869 and 1886). The castle is one of these famous Bavarian castles founded and commissioned by König Ludwig II and is a good example for demonstrating the visualisation and modelling tools in cultural heritage applications.

Reflectance Image

For a lot of applications in the field of architecture and cultural heritage not only geometry is enough but also the visual information.

In the "perspective mode" the user like e.g. the architect or civil engineer can generate a perspective photorealistic view from every single viewing direction, whereas the "overview mode" enables the viewer an all around view (see figure 11).

figure 11: The figure shows the different modes for the reflectance image. *Upper image*: "Overview mode" *lower left image*: "perspective mode"; *small image*: 3D point cloud

Modelling

Figure 12 shows a 3D CAD model of König Ludwig's study of Schloss Neuschwanstein. The room has been surveyed from two different viewpoints. Targets have been used to match the scans together and to refer each scan to a local coordinate system.

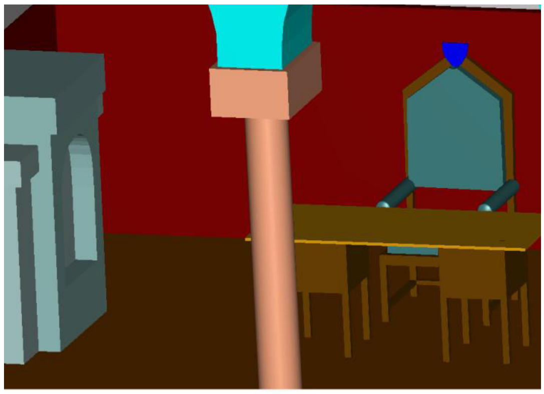

figure 10: The figure shows a CAD model of König Ludwig`s study.

Colour mapping

Beside the accuracy of geometry and the modelling of CAD primitives costumers often require additional a coloured visualisation for demonstration purposes. The results of the colour mapping are demonstrated in **figure 11**: *Image 1* shows a coloured scan of König Ludwig`s study (the colour was taken with the Olympus CAMEDIA), whereas the lower images show scans of the throne room:
Image 3 and *5* were taken with the Olympus CAMEDIA and demonstrate the smooth colour cross over between overlapping images; *Image 2* and *4* were taken with the DLR panoramic camera and show a 3D point cloud.

figure 11: The figure shows the result of the colour mapping process (see text).

5. CONCLUSIONS

With the developed visual laser scanner, the control software and the software for model generation, very powerful tools are available that are suitable for a lot of surveying tasks. The developed laser scanner offers high accuracy measurements in conjunction with a high sampling rate and large dynamic range in reflective properties of object surfaces (highly reflective to absorbing). In combination with the DLR panoramic colour camera or a common (low cost) CCD camera respectively, a precise and accurate monitoring of the actual environment is achieved.
Together with the modelling tools implemented in LFM a broad variety of applications can be modelled semi-automatically.

6. ACKNOWLEDGEMENTS

The authors would like to thank all involved institutes. Especially the head of the Institute of Robotics and Mechatronics at the German Aerospace Center (DLR), Prof. Dr. Ing. Hirzinger and the Laser Group at this institute for the excellent cooperation, as well as the Institute of Optical Information Systems at the DLR for their contributions regarding the Eye Scan Camera. Our special thanks is to the institute for Forest Growth at the University of Freiburg for the good cooperation in the research project Natscan.

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