3D Laserscanning for Engineering and Architectural Heritage Conservation

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ABSTRACT:

Laserscanners are used more and more as surveying instruments for various applications. With the advance of high precision systems, capable of working in most real world environments under a variety of conditions, numerous applications have opened up. The developed IMAGER 5003 is a state-of-the-art, high precision, high speed laser scanner that provides accurate measurements.
In order to monitor scenes by means of range and reflectance images, the IMAGER 5003 is based on a phase-shift measurement principle. In combination with a newly developed and patented scanning system, the system provides a wide field of view of 360° (horizontal) x 310° (vertical) with an image resolution of up to 36,000 x 20,000 pixels within one single image. Scanning time for a full scan depends on the section to be scanned and the number of measured points – for a standard image 360° x 310°, 8,000 x 8,000 pixels less than minutes. The IMAGER 5003 measures both, range and reflectance images at the same time. 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 identification, surface classification and documentation purposes.
To realise surveying tasks in architectural, archaeological and cultural landscapes conservation, the point clouds measured by the laser radar are combined with a specially developed colour camera providing a panoramic image of the 3D environment. The camera is developed by the DLR and provides a good resolution so that images can be mapped onto the point clouds of the IMAGER.
This paper reports design and applications of the Z+F IMAGER 5003 and the DLR panoramic camera. It focuses on accuracy of the system and reports the realised approach from physical measurement of point clouds to coloured point clouds in the end. It shows results from two cultural landscape conservation projects – one inside and one outside measurement – and gives an outlook to further work in the laser scanning development area.

1. INTRODUCTION

1.1 Laser scanner for surveying

The visual laser scanner IMAGER 5003 of Z+F (Fig.1) is an optical measuring system based on the transmission of laser light. 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.
The laser scanner is designed for non-tactile, high performance measurements with high robustness and accuracy. 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 270° vertically (elevation), the scene to be modelled has to be surveyed only from a few points of view. Together with the high performance measuring device (up to 625,000 points per second), this enables the user to survey the scene in a very short time. A typical scan with 4,200 rows and 10,000 points per row is completed in less than 180s. As it is often not necessary to take a scan of the whole environment, it is also possible to define a special window which is intended to be surveyed. Important objects can be measured down to the smallest details with this feature, as you can easily set a very high resolution for this window. The maximum resolution of the sensor is up to 20,000 rows with up to 36,000 points which results in an excellent area coverage and resolution of small structures.

Figure 1: IMAGER 5003

The laser scanner can operate in total darkness as well as in daylight. This facilitates measurement, since no additional illumination is needed. This fact can be of particular importance for cultural sites where certain areas, castles or churches, are difficult to illuminate.
The great advantage of the laser scanner is that the data is stored directly on a computer during the measurements and therefore is digitally available. The laser scanner is controlled with a standard PC or laptop. The control program (see chapter 2) is user-friendly and easy to understand, so that even untrained people can take scans without problems. The point cloud, which is the result of a measurement, has to be transformed into a CAD model for documentation purposes. This transformation is a semi-automatic process, done by special algorithms of programs which are developed especially for processing the point clouds.

1.2 DLR Panoramic colour camera

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 line chip 360° to achieve a full view of the environment. By using three line chips with each 10,000 elements a high resolution can be achieved with the imaging. Three lines (RGB) provide each 16 Bit information of the environment and guarantee a high dynamic range with monitoring.
The resulting images consists of a maximum of

Figure 2: Panoramic camera

10,200 by 500,000 pixels each containing three 14bit RGB values. The image is stored by a specially developed frame grabber onto the hard disk of a computer. A typical scan (10,000 x 30,000) usig a special optical lens system by 35mm optical focus length by the DLR camera takes about 3min (normal light) up to 20min (artificial illumination), mainly depending on the ambient illumination conditions and the number of rows to be measured with the camera.

2. SOFTWARE FOR DATA VISUALISATION AND MODELLING

2.1 Operator software for IMAGER

The operator software is designed for the scanning in the field. 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. By selecting the low function – enabling more than 12 million points to be scanned in less than 20s, a preview of the area to be scanned in detail can be measured and afterwards selected to be rescanned using a higher point density.
The Operator integrates the software package LF Viewer for visualisation purposes and online data measurements by means of a so called "virtual surveying" functionality.

2.2 LF Viewer

Directly after the measuring, the first results can be seen on the computer. The surveyed area is shown on the screen as a grey-coded reflectance image. It is similar to a black-and-white photo and therefore does not require much experience to interpret.
After each scan, the surveyor can see directly in the reflectance image (Fig. 3) the 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.

Figure 3: Reflectance Image

Another way of checking the scan is with the grey-coded range image. It is the complimentary image to Fig. 3, 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.
To get an overall view of the scanned area, the 3D window is essential (Fig. 4). 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 points of view. Like in the reflectance image, hidden areas can be easily detected in this view.
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, 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 in the field.

2.3 LF Modeller

Light Form Modeller (LFM) has been developed specifically 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.

Model construction takes place on a hierarchical basis, that is to say objects can be constructed from smaller components and grouped to form an assembly. Once a complex object has been created, it can be cloned or saved as a library component. Using a unique method of connectors, objects having these connectors can be simply snapped together to form larger groups of objects. This approach is particularly useful where a complex object appears in a model many times and the user needs to instantiate another instance of an object at a specific place.

Figure 4: 3D Point cloud by IMAGER 5003

Conversion from 3D point data into CAD objects is facilitated using a range of specifically developed fitting algorithms which have been developed to be both robust and accurate. It is an interactive conversion process, as the user selects specific groups of points and then directs the program to automatically find the best fit CAD representation of this object. This approach leads to very swift construction of the model even for users new to the system. After doing an automatic segmentation, a semi-automatic fitting of pipes and planes is possible with some interaction required. The LFM fitting algorithms are extremely robust to noise and outliers, so that they still work even if the quality of the points is not as high as usual, which may happen at certain very dark surfaces. Meshing is another method of processing the data obtained by the laser scanner. It is extremely useful for objects with complex and free form surfaces like statues or castles. Meshing takes the cloud of data points and produces a triangular mesh which closely approximates the surface formed by the cloud of points. Point clouds arriving to be meshed can vary immensely in density, overall size and surface complexity, so the meshing system has been designed to be able to deal with these variations on a totally automatic basis.

2.4 LF Architect

LF Architect has been developed especially for the generation of architectural 3D models. It has been written as an add-in for AutoCAD for the editing of data resulting from the IMAGER 5003 in architectural and engineering surveying. Like in LFM, the evaluation is carried out in three steps: image processing, control point surveying and getting the orientation of each scan. Orientation is achieved by bundle calibration with CAP or BETAN / NEPTAN. The orientation is a fully automatic process. The targets and the target numbers are identified by a special algorithm developed especially for the large files of the laser scanner. As the files generated by the laser scanner are very large, LF Architect was designed to generate the result automatically overnight in batch jobs or to export point clouds directly in CAD packages like AutoCAD. The output of the software can be a mesh, floor plans or special sections. Orthophotos can be generated directly from the reflectance images. Panoramic camera images can be integrated into the evaluation process, thus allowing to generate coloured models with original surfaces.

3. APPLICATIONS

For houses and/or monuments it is essential to generate a model consisting of the actual structure and to generate drawings for architectural purposes. For most applications not only geometry is enough but also reflectance and if possible colour information is necessary to fulfil requirements of architects. In order to fulfil three dimensional geometric measurements with colour information, we use two systems, the IMAGER for geometry and reflectance measurements in combination with the panoramic colour camera.

In the following two different applications for cultural heritage applications are demonstrated using both systems:

Figure 5: Colour image of panoramic camera

<u>Castle in Sweden:</u>

In the next example the inside of a castle in Sweden (Stockholm) had been scanned and surveyed by using the Z+F IMAGER 5003 and the Panoramic Camera. The task was to survey some rooms in the castle and make a 3D colour model as well as orthophotos for documentation purposes.

Figure 6: Reflectance Image (section)

Figure 7: Panoramic Image (section)

The surveying was performed in less than one day and the modelling afterwards took approx. 1 week. Especially the superimposing of colour information was quite hard, as the requirement was to have not even a single hidden area. Therefore not only with the modelling but also with the surveying it was really important to scan every small detail.
Figure 6 and 7 show the measured raw data of the Z+F IMAGER 5003 (Figure 1) and of the DLR camera (Figure 2).

Figure 8: Orthophoto of one wall in castle

These information are combined and result in both the orthophoto shown in Figure 8 and the 3D colour point cloud in Figure 9, superimposed from measurements of the IMAGER and the DLR camera.

Figure 9: 3D Colour point cloud

<u>Castle Neuschwanstein:</u>

In the next example the inside of the castle Neuschwanstein had been scanned and surveyed by using the Z+F IMAGER 5003 and the Panoramic Camera (DLR).

As a result, the coloured point cloud of the IMAGER is shown in Figure 10. The raw data sets measured by the IMAGER and the DLR camera are the data sets shown in Figure 3 – 5.
The results achieved above open a new dimension with laser scanning in the cultural heritage area.

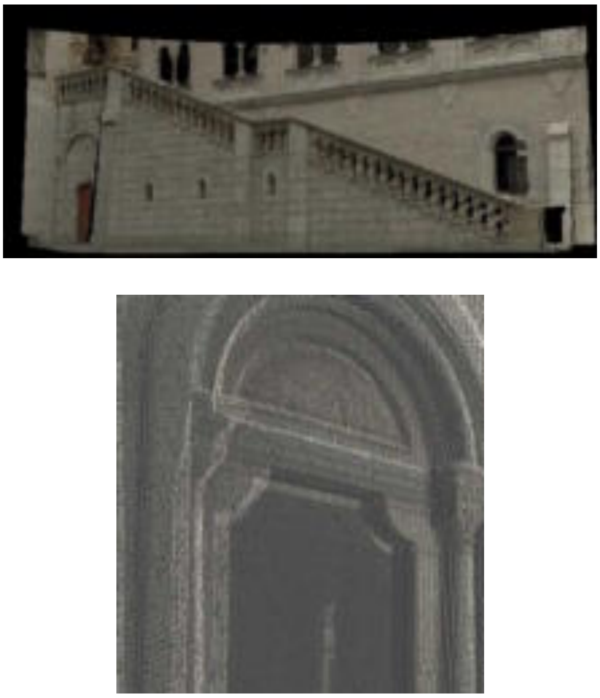

Figure 10: Coloured point cloud of Neuschwanstein (section)

4. 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 most cultural heritage 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 a precise and accurate monitoring of the actual environment by means of colour point clouds is achieved. This is unique due to its high precision and quality. Together with the meshing tools implemented in LF Architect a broad variety of cultural heritage can be semi-automatically modelled.

In a next step further improvements on mapping colour and geometry by means of raw data will be researched with several international partners in research projects.

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